GALBRAITH AND HAUGHTON'S

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MANUAL

OF

GEOLOGY.

GALBRAITH & HAUGHTON'S SCIENTIFIC MANUALS.

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MANUAL

OF

GEOLOGY.

BY

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PREFACE TO THE SECOND EDITION.

In publishing a second edition of my Manual of Geology, a few words are necessary in reply to comments made upon the first edition by two classes of reviewers; who may be divided, after the manner of Peter Ramus, into those that read the book and those that did not.

To the latter, who were, doubtless, misled by the modesty of the preface, I would remark, that my book is not a Compendium made from Dana, Lyell, and Jukes, although I hope it may prove to be a useful introduction to the works of those writers; and I have no doubt they will agree with me when they have read it.

The other class of critics, who have done me the honour to read my book, admit that my facts are correctly stated, and that I have drawn just inferences from those facts with respect to inorganic matter, but complain that I have hesitated to draw similar inferences with respect to organic beings; and finally allege that my view of Creation is essentially Anthropomorphic, and that I represent the Creator as having set about the formation of the world, much in the fashion in which an intelligent shoemaker would make a pair of shoes.

My apology for taking the Anthropomorphic, instead of the Pithecomorphic view of nature, is that I am a Man, and not an Ape, and therefore cannot help doing so; and I admit that my idea of the Creator is perhaps as clumsy as the illustration supposes, and that I can no more imagine an abstract

Creator, *à la* Lamarck or *à la* Darwin, than Martinus Scriblerus could imagine an Universal Lord Mayor, without his Horse, Gown, and Gold Chain.

In the Mineral Kingdom, we do not believe in the separate creation of calc spar, gypsum, &c., because we see that they are formed every day before our eyes out of oxygen, sulphur, carbon, hydrogen, and calcium, &c., and we regard the latter as ultimate facts explicable by the hypothesis of an Almighty Creator; and I cannot see why in the Vegetable and Animal Kingdoms we should not follow the same method. As soon as experiment and observation shall have proved that lower species can be transformed into higher species by natural causes, we may cease to regard them as Ultimate facts, to be explained by the hypothesis of a Creator, and retain on our list of Ultimate facts those

species only, which, like the simple bodies of Chemistry, have not been proved to derive their origin from other species by natural laws.

Such a transformation of species, in my opinion, has not yet been proved in a single case, and many of those who have undertaken to prove it seem incapable of understanding the difficulties of their task, or the requirements of really exact science.

In the present edition some defects have been supplied, some errors of style corrected, and finally a Geological Gymnasium of upwards of six hundred problems has been added, in the solution of which it is hoped that Geologists, both strong and weak, will find an agreeable occupation for idle moments.

TRINITY COLLEGE, DUBLIN,
May 1, 1866.

PREFACE TO FIRST EDITION.

In teaching Geology the Author has often felt the want of a Manual for his class containing a general conspectus of the Science. It is hoped that this want will be to some extent supplied by the present Lectures, which may be regarded as an introduction to the more systematic treatises of Lyell, Dana, Jukes, and others. The Lectures are printed nearly as they were delivered, from notes, in 1862, having been taken down by a shorthand writer for the Author.

Trinity College, Dublin,
June 16, 1865.

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GEOLOGY.

LECTURE I.

ORIGIN OF THE GLOBE—ACID AND BASIC MAGMAS—ZONE OF SULPHURETS—ORIGINAL COMPOSITION OF ATMOSPHERE—PHYSICAL CONDITIONS OF LIFE—IMPORTANCE OF NITROGEN—CHANGE OF PHYSICAL CONDITIONS.

GEOLOGY is the science that investigates the history of the earth and of its inhabitants.

During a previous course of lectures, I directed attention to the facts connected with the history of the earth itself. During the present course I shall discuss the more interesting, though not more important, question of the history of the earth's inhabitants. But before proceeding to the history of the earth's inhabitants, which many writers have defined as including the whole of geology, it is necessary to say a few words, of an introductory character, regarding the physical conditions that were necessary to be established on the earth before it could have had any inhabitants at all. And afterwards I shall invite your consideration of the conditions under which the earth's inhabitants have assumed the fossil state, and have so become the subject of our notice and study as geologists. During the remainder of the course our whole attention will be directed to an examination of those living creatures themselves, and of their history on the globe.

I have before shown you the high probability there is, that Laplace's nebular hypothesis is the nearest approach that we are capable of making to an astronomical history of the origin of our globe. But it is not sufficient for us to rest contented with this speculation, which gives an account of the origin of the globe as one of the group of planets that circulate around the sun. We must, as geologists, enter more into detail, and seek to inquire into the application of the theory of Laplace to our own planet. And here we find that modern science has placed at our disposal a number of facts with which Laplace and other writers who have adopted his theory were not acquainted. We know to a very great extent the chemical composition of the crystalline rocks that constitute the outer portion of our globe; and we therefore know how completely erroneous the speculations of Laplace and other mathematicians were, who supposed that the density of the rocks that compose the earth is dependent merely on their mutual mechanical pressure.

It is, by these writers, in fact, supposed, that as we descend into the globe we find strata which are more and more dense by virtue of the law of compression, whatever it is, proper to the substance of which the earth is composed. This, you will observe, is essentially founded on the notion that the earth is a homogeneous body, composed of strata of the same material, differing only in the pressure to which they are subjected. Now, from the researches of modern chemists and geologists, we know that this is not the case, and that the specific gravity or density of the strata composing the earth's mass depends much more on its chemical

composition than on pressure or merely mechanical conditions.

According to Durocher,* we have evidence that the first and second layers of the globe are composed of totally different materials. The outer layer, which he calls the Acid Magma, corresponds with the granites; and the inner, or second layer, which he calls the Basic Magma, corresponds with the trap rocks and the greenstones. The average composition of the outer layer, or granitic crystalline rocks of the globe, is shown in the following Table:—

Silica,	71.0
Alumina,	16.0
Potash,	4.5
Soda,	2.5
Lime,	1.0
Magnesia,	1.0
Oxides of iron and manganese,	2.5
Water, fluorine, carbonic acid,	1.2
	99·7

The other, or basic magma, falls from 71 to 51 per cent. in the quantity of silica; and the loss is made up by the bases. The following is its average composition:—

Silica,	51.5
Alumina,	16.0
Potash,	1.0
Soda,	3.0
Lime,	8.0
Magnesia,	6.0
Oxides of iron and manganese,	13.0
Water, fluorine, carbonic acid,	1.3
	99·8

* I have added as an Appendix (A) to this Lecture a translation of Durocher's remarkable Essay.

These two Tables represent Durocher's view of the chemical composition of the acid and basic magmas composing the first and second layers of the globe. The following contains the quantities of oxygen in each material :—

	Acid Magma.	Basic Magma.
Silica,	36.86	26.50
Alumina,	7.47	7.47
Potash,	0.76	0.17
Soda,	0.64	0.76
Lime,	0.28	2.27
Magnesia,	0.40	2.40
Oxides of iron and manganese,	0.75	2.88
Water, fluorine, carbonic acid,	1.06	1.15
	48·22	**43·60**

The total result, you observe, is to give 48.22 per cent. of oxygen in the acid magma. One half, therefore, or nearly one half, of granite consists of oxygen. But when you come to the basic magma, you observe, by adding up the column of oxygen, that we get only 43.6. The first fact, then, that I would call your attention to, with regard to Durocher's first and second layers of the globe, is, that the outer layer is more highly oxidated than the inner layer.

There can be very little doubt of the general correctness of Durocher's theory. In fact, something equivalent to it has struck chemists from the time they began to study the composition of rock masses. I believe Humboldt was the first writer who directed attention forcibly to the circumstance, that, whereas the organic productions, the plants and animals, of different climates vary

with those climates, so that while the traveller, in passing from one to another, is astonished at finding the change from the familiar forms he was accustomed to, to strange forms that he has never before seen, he yet finds, as Humboldt says, with pleasure, in the rocks, the same familiar faces that he remembers from childhood in the rocks and hills about his own home. We are able to add to Humboldt's statement of the sameness of character of the crystalline rocks, that there is an almost absolute identity in their chemical composition. This piece of granite which I hold in my hand, a very fine specimen from the Three-rock Mountain, close to Dublin, may be regarded as an excellent specimen of the typical granite of Durocher. I find, from a great number of analyses of granite made everywhere, that the granite that runs from Dublin to Ross has as nearly as possible the mean composition of granites. If we take granitic rocks from China, from Greenland, from Australia, from the antarctic Continent, from Europe—from every part of the globe, and analyze their constituents, we find they all have a composition very close to the average composition of Durocher's acid magma. I would alter slightly some of the figures, if I were writing its composition; but, on the whole, it is somewhat close to the result I myself obtained; and I find that the granite of Leinster is, as nearly as possible, a type granite. Here is a specimen of the granite of Cornwall, totally different in appearance from that of Leinster; but when analyzed it turns out to have the same chemical composition; and this very remarkable piece from Donegal differs somewhat from the others in chemical composition, and differs very sensibly in its appearance. You are not

to be led by the difference in the appearance of granites, or, indeed, of any crystalline rocks, too hastily to the conclusion that they are of different composition from the rocks from which they vary much in appearance, because we know that the larger or smaller size of the crystals in these rocks is a circumstance not depending on their chemical composition, but on the conditions under which they were cooled.

In proof of the sameness of composition of large granite masses from different localities, I here give the mean of six analyses of various specimens from Mont Blanc, and of eleven analyses of different portions of the granite axis of Leinster*:—

	Mont Blanc.	Leinster Range.
	Mean of 6 Analyses	Mean of 11 Analyses.
Silica,	72.80	72.07
Alumina,	13.23	14.81
Iron (peroxide),	1.98	2.22
Iron (protoxide),	1.48	0.30
Manganese (protoxide),	0.40	—
Lime,	1.34	1.63
Magnesia,	0.62	0.33
Potash,	3.62	5.11
Soda,	3.69	2.79
Water,	0.76	1.09
	99·92	**100·35**

The following two specimens of syenite may be regarded as representing the basic magma of Durocher. One is from Lough Anure, in the county of Donegal; and the other is from West Aston, in

* "Journal of the Geol. Soc. Dub.," vol. ix., p. 329.

the county of Wicklow. They are quite different in appearance, but have a similar chemical composition :—

	Lough Anure.	West Aston.
Silica,	49.20	52.08
Alumina,	18.32	15.60
Iron (peroxide),	7.12	5.75
Iron (protoxide),	1.95	2.57
Lime,	9.72	6.52
Magnesia,	7.11	8.40
Soda,	1.92	2.92
Potash,	1.72	3.80
Manganese (protoxide),	1.00	—
Loss by ignition,	1.20	2.24
	99·26	**99·88**

We adopt, then, as chemical geologists, Durocher's hypothesis, as to the first and second layers of the globe. And as the globe cooled, we know that fissures formed in it, evidence of which fissures still remains in our mountain chains and metallic lodes. These fissures themselves are filled from below with a class of compounds totally different from the acid, or from the basic magma. They are filled with sulphur salts, containing arsenic, antimony, selenium, and other bodies, as well as sulphur; and all our metallic ores, as is now generally supposed, whatever be the condition in which they may be found in our mines, originally came from below, sublimed from the interior of the earth as sulphur salts. Now, these sulphur salts contain not a single particle of oxygen; and the ores in metallic mines which contain oxygen derive it from the action of the water and carbonic

acid of the atmosphere. That is an action from above downwards; whereas an action from below upwards originally filled these fissures of the ground with sulphur salts. The oxygen came from above; the sulphur and arsenic from below. Therefore, I think, without much stretch of imagination, we may suppose that inside these two layers of Durocher—the granitic and the trappean layers—we have in the interior of the globe a layer composed of these sulphur salts.

Many geologists think that some light is thrown on the astronomical history of our globe—in fact, on its physical history—by a consideration of the meteoric stones that fall through our atmosphere. A very remarkable fact about these meteorites is this, that they are either meteoric stones or meteoric iron. Meteoric iron is a compound of iron and nickel, and contains no oxygen whatever. The meteoric stone has a very uniform chemical composition, and contains 22 per cent. of oxygen. Now, there can be no doubt whatever that these meteoric stones, or meteoric iron, are revolving round the sun as planets; and that the earth in her course, from time to time, has some of these bodies entangled in her atmosphere. They penetrate the earth's atmosphere to a considerable distance, assuming that black crust, or layer, which you see upon the surface, and which is formed by the intense heat developed by the friction of the stone as it passes through the air. Having traversed the air for a certain distance, the meteorite falls perpendicularly to the ground. It is a mistake to suppose that these meteorites come nearly horizontally; they have almost all been observed to fall nearly vertically. The meteorite enters the atmosphere of the

earth with a velocity of something like 18 or 20 miles per second—in fact, a planetary velocity. It forms at once a halo of densely compacted air in front of it, and a vacuum behind; and it is this vacuum, causing the air to close behind, as the meteorite passes through it, which gives rise to the explosion that is heard, like thunder, just before the fall of the meteoric stone. During that planetary flight through the atmosphere the meteorite becomes heated, and its surface acquires its thin pellicle of glass. Whether we regard the meteoric stones, or the meteoric iron, we notice the comparative absence of oxygen from these bodies, and are led to speculate still further as to the nature of our own globe (considering that we know that the sulphur salts that fill the lodes and fissures in the ground contain no oxygen), whether in the deep interior of the earth itself there may not be masses of meteoric iron and nickel quite analogous to those shooting about and revolving round the sun in interplanetary space.

Whatever opinion we may form as to the interior of the earth, however, there can be but one opinion as to the importance of the part which is played by oxygen and other cognate bodies at its surface. I have said that it is necessary to consider the physical history of the globe before we consider the history of its inhabitants; because we can show in the strictest manner that, unless certain physical conditions existed on the surface of our planet, no organic life of any kind, such as we know it here, would be possible. We have every reason to believe that all these physical conditions belong to the atmosphere which surrounds the planet, and are not to be regarded as mineral

conditions at all. In a planet which contained no oxygen in its atmosphere, no such rocks as those could exist, which contain 48 and 43 per cent. of oxygen. In a planet that contained a smaller amount of oxygen than the earth does, it is quite possible that rocks of the composition of the meteoric stones might be the most highly oxygenated rocks on its surface, and that they would constitute its outer layer. But inside that outer layer of oxidized rocks, whatever it was, there would be found in the interior, as there doubtless is in the interior of our own globe, masses of mineral matter containing no oxygen whatever.

Not only had we, originally, an atmosphere of oxygen, but also of hydrogen, carbon, chlorine, and water. These bodies all belonged to our atmosphere, and are not to be regarded as mineral. The oxygen, the carbon, and the hydrogen, appear in the form of carbonic acid and water. I presume that, in the original heated condition of the globe, there were oxygen, carbon, and hydrogen, and that the carbon and hydrogen rapidly became carbonic acid and water, and so appear in that form.

Oxygen and water are found abundantly in minerals; because, as we see, the outer layer of the globe is so oxidated that it contains nearly 50 per cent. of oxygen, and the next layer contains very nearly as much. Therefore, oxygen and water must enter largely into the composition of almost all rocks and minerals on the surface of such a planet as ours.

Chlorine is more sparingly distributed, and so is carbonic acid. The chlorine appears to exist principally in the form of sea salt. The chlorides that are mineral are exceedingly few. There is the

chloride of copper, a rare substance; and there are a few other chlorides to be found here and there; but, considered on a large scale, the only great mass of chlorine that is to be found on the surface of the earth is common sea salt, and this, I have no doubt, existed originally in the form of chlorine in our atmosphere.

The nitrogen still uncombined in the atmosphere does not enter in any manner whatsoever into the composition of minerals, except such minerals as are themselves the result of the putrefaction of organic bodies.

The carbonic acid, which is one of the most interesting of the substances contained in the primitive atmosphere, exists in a mineral condition only in two shapes—either as coal, or in carbonates. And when considering these carbonates, we set aside bodies that are seldom found, such as carbonate of barytes and other minerals of that sort, and confine our attention to the carbonate of lime, and limestones. Now, whether we regard the coal or the limestone as the product of the carbon, they both point to organic life. The coal is confessedly and obviously nothing but the result of vegetation. It is, in fact, the preserved remains of trees and plants that have lived upon the globe, that have taken carbon from the carbonic acid of the atmosphere, and have fixed that carbon in their tissues by means of a vital property which is universal in the vegetable kingdom. On the other hand, in the carbonates of lime, although the lime is supplied, and the magnesia in abundance—8 per cent. of lime, and 6 per cent. of magnesia—in the basic magma of Durocher, yet we must seek elsewhere for the carbonic acid that enters into combination

with this lime, and makes it limestone. In Trap rock the lime exists as a silicate, which is easily decomposable by the joint action of water and carbonic acid; and in this manner, there can be no doubt that the original carbonic acid of the atmosphere entered into combination with the lime of the basic magma, for which it has a most powerful affinity, and so laid the first foundation of the possibility of the existence of those animals, the corals and others, whose skeletons constitute the greater part of the substance of all the limestone rocks, which may be regarded as the result of the joint action of two causes—of the organic life of the corals and minute polyps which fixed this carbonate of lime in their skeletons, and of the chemical precipitation of the carbonate of lime from its solution by water. These two causes combined have given us our limestone rocks, which are themselves as much an evidence of the existence of organic life on the surface of the globe as the coal beds are.

Lastly, when we come to the nitrogen, we know the important part which it plays in the formation of the tissues of all animals. In fact, I believe that no formal definition of an animal has yet been given much superior to the chemical definition—" An organic substance which, when dried at 212°, contains not less than 3 per cent. of nitrogen." There is no plant that answers that condition; and most animals do fulfil that condition. This, though a fanciful definition, expresses a most important fact, namely, that nitrogen is the one condition essential to the existence of the animal kingdom. If we imagine a planet whose atmosphere contained no nitrogen, that planet might

certainly possess a vegetation on its surface; but it never could have an animal kingdom, such as we see to adorn our own planet. And if we suppose carbonic acid also to be absent, neither animal nor vegetable life, according to our knowledge of the subject, could by any possibility exist upon that planet. It is a favourite speculation with metaphysicians—one which, of course, we cannot solve, and that is a consideration that perhaps renders it more attractive to this class of thinkers—whether the earth is a type of all the other planets in her structure and peculiarities, or whether she is an exception. I confess myself very strongly disposed to lean to the side of those who consider her to be a remarkable exception. We have no right whatever to assume that, because the earth is inhabited, therefore all the other planets are inhabited. We know it to be nearly certain that, owing to the absence of an atmosphere, our moon is not inhabited; and, from considering such questions as I have brought before you to-day, it would appear that the possibility of the earth's being inhabited at all is dependent on the large quantities of nitrogen and carbonic acid in her atmosphere. It is quite possible that the other planets may not have the same quantity of oxygen, carbon, and nitrogen in the composition of their atmospheres that our planet has; and therefore, if we are in a condition to speculate on this matter at all, it is very possible that the earth may, in her constitution, be a remarkable and unique exception to all the other planets.

As the earth cooled down from the original heated condition supposed by Laplace's hypothesis, her layers ranged themselves according to their

specific gravities in order, those specific gravities depending much more on the chemical composition of the layers than on the pressure to which they were subject, and increasing with the depth below the surface; fissures gradually formed in the outer surface of the earth, and a free communication between that outer surface and the deeper layers of the interior was opened up ; and the earth again, during this process, was surrounded with its atmosphere, which consisted originally of steam, oxygen, nitrogen, volatilized carbon, chlorine, and perhaps some sulphur. As the process of cooling went on, the earth solidified, and the oxidating influence of the atmosphere on the cooling masses below commenced. Gradually the whole of the first and second layers were oxidated with the maximum amount of oxygen that they could take from the atmosphere;* and the oxidating influence failed to penetrate deeper into the layers, in which the sulphur salts were situated, and which ascended by sublimation into the fissures constituting our lodes. Then gradually the carbonic acid of the atmosphere and the chlorine entered into combination with those substances at the surface of the earth for which they have the greatest affinity, constituting the salt of the sea, and the materials from which the first created polyps and corals began to construct the limestone rocks. Thus we see the reason why limestone should have so remarkable a place in the history of the globe—why it should be so rare in the older rocks, and appear to increase in proportion as we advance in the history of the earth, becoming more and more abundant; and not

* See Appendix (B), On the Origin of Granite.

only more abundant, but every given thickness of it corresponding to a greater amount of organic life than the limestones of the older rocks.

If we take this broad and general view of the physical history of the globe, we shall see how the latter was gradually prepared by its Creator to become a fit abode for the successive forms of organic life that He was afterwards pleased to place on it; and I think, when you consider the intimate relation that exists between these physical conditions and the organic life that flourishes upon it, you will see the great importance of not separating these two branches of the study of geology from each other.

APPENDIX (A).

ESSAY ON COMPARATIVE PETROLOGY.

(TRANSLATED FROM DUROCHER.)

Object of the Memoir.—This essay gives the general results of a series of researches in which I have for a long time been engaged on the igneous rocks, and which are not yet completed. Some of them, however, have already appeared in various journals, viz., "Voyages en Scandinavie;" "Comptes rendus de l'Academie des Sciences" (tom. xx. p. 1277; tom. xxiii. p. 978; tom. xxv. p. 208; and tom. xliv. pp. 325, 459, &c. &c.); the "Bulletin de la Société Geologique" (2nd ser. tom. iv. pp. 409, 1018; and tom vii. p. 276); and the Memoirs of the same Society (2nd ser. tom. vi. first part).

For many years the eruptive rocks have been the subject of important investigations, both in France and Germany; but these investigations have given rise only to works of detail, of which the object is to determine the mineral species found in the rocks. The present essay is a "Memoir on Comparative Petrology," and ought to be considered as an attempt at a general synthesis of the pyrogenous rocks, considered in the fourfold point of view,—of their Chemical constitution, their Mineralogical composition, their Eruption, and their Classification.

PART I.—REDUCTION OF ALL THE IGNEOUS ROCKS TO TWO MAGMAS.

Office of Silicon in the Mineral Kingdom.—In the mineral kingdom, Silicon performs a part analogous to that of carbon in the organic kingdom; and in its behaviour, as a polybasic acid, silica unites with the oxides in various proportions, and thus gives rise to numerous combinations. Most of the mineral species which thence result, and especially those which enter into the composition of the crystalline rocks, arise from combinations of elements which are always the same, and whose total proportions in the

mass containing them vary only within narrow limits. In seeking the mineral silicates, whose aggregation constitutes rocks, it is not necessary that each association forming a distinct rock mineralogically should also correspond to a special chemical composition of the Magma which produced it. This appears to me to constitute one of the most important views of the study of rocks; and the researches which I have undertaken on this subject have led me to results remarkable for the simplicity which they introduce into the history of igneous formations, and which, besides, being founded on experimental data, appear to me to agree perfectly with geological observations.

All Igneous Rocks derived from Two Magmas.—An immense number of consequences may be logically derived from the following proposition, the proof of which I shall furnish presently, viz.:—*That all igneous rocks, modern and ancient, were produced by two Magmas, which coexist below the solid crust of the globe, and occupy there each a definite position.*

These two Magmas have undergone but slight changes of composition from the most remote geological epochs; and, moreover, they differ essentially from each other by means of well defined characters. The one may, from its excess of silica, be called the Acid Magma; while the other is comparable to a basic salt; for its silica is not in sufficient quantity to saturate its metallic oxides. The difference of silica in the two Magmas is in the proportion of 7 : 5. They contain nearly the same quantity of alumina; but the Siliceous Magma contains from once and a half to twice as much alkalies, and more potash than soda, while the reverse occurs in the Basic Magma. The first is specially characterized by its poverty in earthy bases, and the iron oxides; of these, it contains from six to eight times less than the other.

The following Table I. gives the composition of these Magmas, and the specific gravities of the rocks derived from them:—

TABLE I.

Proportions of Elements.	Silica.	Alumina.	Potash.	Soda.	Lime.	Magnesia.	Oxides of Iron & Manganese.	Water, Fluorine, Carbonic Acid.	Sp. Gr. of Rocks. 1st. Natural.	Sp. Gr. of Rocks. 2nd. Vitrified artificially.
GENERAL LIMITS OF PROPORTIONS IN THE IGNEOUS ROCKS.										
1. Siliceous,	62 to 78	11 to 20	3 to 6	1 to 6	½ to 2	½ to 2	½ to 4	½ to 3	2.4 to 2.7	2.35 to 2.46
2. Basic, .	45 to 58	11 to 20	⅓ to 3	1 to 6	5 to 12	3 to 12	7 to 20	½ to 4	2.8 to 3.2	2.5 to 2.84
MEAN PROPORTION IN THE TWO MAGMAS.										
1. Siliceous,	71.0	16.0	4.5	2.5	1.0	1.0	2.5	1.2	2.65	2.40
2. Basic, .	51.5	16.0	1.0	3.0	8.0	6.0	13.0	1.3	2.95	2.72

By combining the results I have obtained by chemical and mechanical analysis with those of analyses already published by various mineralogists, I have established that igneous rocks of crystalline texture, and almost all compact or vitreous masses, formed by fusion, and wrongly considered as minerals, are derived from one or other of these Magmas. To the first are referable all the granitic rocks, including the eurites, quartziferous porphyries, and petrosilex, the trachytes, phonoliths, perlites, obsidians, pumices, and lavas, with vitreous felspar. To the second belong diorites, ophites, euphotides, hyperites, melaphyres, traps, the basalts, and pyroxenic lavas.

Origin of Mineralogical Differences in Igneous Rocks.—I should also remark that, if we analyze various kinds of the same group of rocks—granites, for example—we often find more difference in the relative proportions of elements between two specimens of the same type of rock, than there is between granite and a rock altogether dissimilar in appearance—say a trachyte or pumice. We should conclude from this fact, that in rocks derived from the same Magma differences of mineralogical composition arise less from their elementary composition than from conditions of pressure, temperature, and in general the circumstances of their cooling; that is to say, from conditions of an *external* rather than an *internal order*. The Magmas which have produced the igneous rocks are comparable to baths containing many metals in a state of fusion, and which, in setting, are divided into alloys, different according to the circumstances of their cooling, even when the original bath has the same composition.

Products of the Zone of Contact of the two Magmas.—Moreover, the zone of contact of the two Magmas should give out products of an intermediate character; and this is, in fact, the case; and from this zone appear to arise the syenites, the protogenes rich in talc, the trachytes rich in pyroxene and amphibole, and various porphyries which are intermediate between granitic or trachytic porphyries, and amphibolic or pyroxenic porphyries. These rocks, which may be called *hybrid rocks*, have petrographical and geological affinities of an unsettled character; they seem to belong sometimes to the rocks of the first, and sometimes to those of the second Magma.

Permanence of Separation of the two Magmas.—The upper Magma, which is rich in silica, and poor in earthy bases and oxides of iron, possesses the least specific gravity; and in this respect there are differences among the rocks produced by the two Magmas, from once and a half to twice as great as between oil and water. The separation is still greater, if, in place of considering the rocks in their natural condition, we compare the vitrified products obtained by their fusion: further still, if we refer them to their liquid condition, there ought to be, according to Bischoff's ex-

periments, between the rocks arising from the two Magmas, differences twice greater than those observed in their crystalline state, and therefore from three to four times greater than those between oil and water: from these facts may be deduced the necessary and permanent separation of the two Magmas.

Fluid Zone situated below the Solid Exterior Crust.—The solid crust of the globe, then, reposes upon a fluid zone, composed of two distinct layers: the upper, which is the most refractory, is only semi-liquid, or pasty, in consequence of the predominance of silica, which is characterized by its viscosity; the second layer, which contains much less silica, and which presents atomic proportions ranging from a bisilicate to a sesquisilicate, is much more fluid and dense; and also appears to be very rich in the oxides of iron, especially in certain regions. From this source have emanated those great masses of magnetic oxide which have burst forth after the manner of the igneous rocks; and which in Italy, and the Ural Mountains, as in Scandinavia, are connected with the amphibolic or pyroxenic rocks. In the upper layer are collected, by preference, the lighter or more volatile bodies, such as the alkaline metals, fluorine, boron, &c. &c.; and, in fact, it is in the granitic rocks arising from this layer that we find commonly the fluo- or boro-silicated minerals, as mica, topaz, tourmaline, &c. &c.

PART II.—ON THE CHANGES WHICH HAVE TAKEN PLACE IN THE COMPOSITION OF THE TWO INCANDESCENT LAYERS, FROM WHICH THE ERUPTIVE ROCKS HAVE EMANATED.

Comparative Chemical Composition of the Principal Types of Eruptive Rocks.—It has appeared to me interesting to investigate the changes which have taken place, from the earliest epochs of the globe, in the nature of the incandescent layers constituting the seat of the eruptions: for this purpose it is necessary to compare the principal types of rocks which have burst forth during successive geological epochs. I have determined their average composition, and the limits of the variations which take place in the proportions of their elements, both from my own researches and from the chemical analyses published by various writers, among whom I may mention, in particular, MM. Gmelin, Abich, Dufrenoy, Ebelmen, Delesse, and Ch. Deville. The results at which I have arrived are contained in the annexed Table II.

Changes in the Composition of the Acid Layer deduced from a Comparison of the two great Families of Siliceous Rocks.—The siliceous rocks comprise two great families—the granites and the trachytes: their separation is very definite chronologically, for the former belong to the primary or secondary periods, and the latter to the tertiary, quaternary, and modern periods. If, now,

Hybrid	Mo	3.0 8.0	6.0	1.0 3.0	1.8	3.0 11.0	6.0	" 3.0	1.0
		1.5 3.0	2.7	3.0 4.0	3.5	7.0 9.0	8.0	" 2.5	1.6
Basic Ro		3.0 9.0	6.3	2.0 10.0	6.0	10.0 20.0	14.0	" 2.0	1.0
		6.0 14.0	9.5	7.0 15.0	9.7	8.0 14.0	11.5	1.0 6.0	2.5
		5.0 9.0	7.6	6.0 14.0	9.3	8.0 19.0	14.0	" 1.0	0.6
		4.0 8.0	6.2	3.0 5.0	4.0	5.0 12.0	9.0	1.0 3.0	1.5
		7.0 14.0	10.2	3.0 10.0	6.5	9.0 16.0	13.8	1.0 5.0	3.2
		7.0 13.0	10.0	3.0 9.0	5.5	9.0 18.0	14.7	0.5 3.0	1.1
		" " "	8.8	" " "	5.3	" " "	12.5	" " "	2.1
		7.0 13.0	10.0	4.0 7.0	5.0	10.0 17.0	14.5	" 2.0	1.0
		6.0 12.0	9.0	1.0 6.0	3.0	6.0 12.0	9.2	" 1.0	0.6
Degradati Basic Ro		" 3.5	0.8	34.0 44.0	39.5	1.0 8.0	3.4	9.0 15.0	13.0

we compare the average composition of the two fundamental types of those families, granite and trachyte, and consider that they represent the most abundant products of the siliceous layer, we shall find that in the long course of ages dividing the primary and tertiary periods from each other, the following changes took place in the composition of the fluid mass which nourished the eruptions, viz., there was a diminution of $\frac{8}{100}$ or $\frac{9}{100}$ in the proportion of silica, and of $\frac{31}{100}$ in the potash; but that the proportions of lime and iron oxides were almost doubled, and that of soda tripled. If, again, we compare the composition of the trachytes of the tertiary period with that of the trachytic lavas of the present epoch (and we may cite as a type lava that of the Arso, which was spread over the isle of Ischia in 1301), we shall find that the proportion of silica has diminished still further, remaining, however, greater than the quantity contained in the various rocks ejected from the basic layer; while the soda has increased by more than $\frac{50}{100}$.

Changes of Composition in the Basic Layer.—Let us see if changes of the same kind have taken place in the composition of the lower ferrocalciferous layer of fluid, including the diorites, &c. The diorites are the most ancient of the basic rocks, and were ejected the most abundantly in the earlier geological periods. But towards the end of the secondary period, and during the tertiary, they have been generally replaced by the pyroxenic rocks, which present three principal types, viz., melaphyre, basalt, and dolerite. Their chemical composition is sensibly different, although they proceed from the same focus; and I have thought that to obtain the composition of the liquid layer from which they proceed, the best method would be to take the mean of the compositions of the three types. We thus obtain a general term of comparison, which I have called in my Table, *Pyroxenic Rock of average composition*, and which represents the whole group of *modern basic rocks* as distinguished from the diorites, which represent the *ancient basic rocks.* By comparing the numbers thus obtained with those presented by the diorites, we can appreciate the changes which have taken place in the ferrocalciferous fluid layer from the primary to the tertiary period. We see thus that there was a sensible diminution of silica and potash, and a notable augmentation of soda and lime. The proportion of soda has continued to increase still later, for our volcanic products contain still more than those of the tertiary period. The proportion of iron appears to have diminished rather than increased; but I should observe that the masses of magnetic oxide are connected with the amphibolic rocks, and it is to this circumstance that the richness in iron of the diorites is due, while a special cause tends to impoverish some of the volcanic products; that is, the influence of chlorine, which carries away the iron in the state of vapour.

Similarity of the changes undergone by the Acid and Basic Layers.—We may recognise a remarkable similarity in the changes experienced by the Acid and Basic layers; in both there has been a decided diminution of silica and potash, while, on the contrary, the proportions of lime and soda have augmented. But the two layers remain, nevertheless, distinct, and the trachytic products which represent the deeper portions of the siliceous layer differ much less in the whole of their elements from the granites (even the most ancient), than they do from the diorites, or from any other product of the basic layer. As to the hybrid rocks which issue from the zone of contact of the two layers, my Table shows that, as well by their chemical composition as in their mineralogical character, they form a sort of tract of union between the two systems, although they seem to approach somewhat nearer to the siliceous rocks.

Causes of this Change of Composition.—The diminution of silica and potash in the modern rocks of the Acid and Basic groups seems to me to arise from the fact, that those elements were concentrated towards the upper portion of the fluid zone, on account of their low specific gravity; and, on the contrary, the proportion of lime should increase with the depth. But the increase of soda in the eruptive products of the later epochs of the globe, an increase which becomes more and more decided down to our own epoch, and which is not in harmony with the changes in the proportions of the other elements, appears to me to be due to a special cause: it appears to be difficult to give an account of it, without admitting the intervention of sea water in the formation of igneous products, at least during the later geological periods. Thus, like M. Abich, I am led by my researches on rocks to consequences having points in common with the explanation which H. Davy had deduced from his studies on volcanic phenomena; but it does not appear to me to be necessary to suppose unoxidized alkaline and earthy metals to exist in the incandescent zone which covers the earth's surface.

Three orders of facts require the intervention of sea water in volcanic phenomena.—The intervention of sea water in volcanic effects appears to me to be based upon three great orders of facts:—

1°. The action of elastic fluids, much more marked at present than formerly, on the phenomena and rocks of eruption.

2°. The nature of these elastic fluids, among which are found in abundance aqueous vapour, hydrochloric acid, and the chlorides and acids of sulphur.

3°. The considerable increase of soda in the more modern of the igneous rocks, whether they be derived from the Acid or the Basic layer; I should add, that this substitution of soda for potash is accompanied by the replacement of fluorine by chlorine.

I might also add that many volcanic products contain, not

merely organic matters, but, according to the observations of M. Ehrenberg, recognisable traces of organized beings, which prove clearly the addition of external elements in the formation of those products, whilst there is nothing similar in the ancient granitic rocks, which constitute purely *endogenous* masses. I am aware that there are certain difficulties inherent in the hypothesis of an intervention of sea water in volcanic action, but these difficulties are not insurmountable; and we must, of necessity, take account of the whole of the facts I have noticed, as tending to the same conclusion.

Circulatory Movement of Soda.—We know, moreover, that the sodiferous silicates are more easily decomposed than the potassiferous silicates: thus in mineral waters, as in the sea water, soda is the dominant alkali. It seems thus destined to a continual circulatory movement: removed from the rocks in decomposition by the infiltrated water, then transported to the sea by running water, it is brought back by deep crevasses to the subterranean foci, from which it issues again, partly as vapour, and partly incorporated in the lavas.

PART III.—EXPLANATION OF THE DIFFERENCES IN CHEMICAL COMPOSITION AND MINERAL CHARACTER OF THE IGNEOUS ROCKS.

Having explained the changes produced, from the earliest epochs, in the chemical composition of the two fluid layers which form the seat of igneous eruptions, I now proceed to compare the composition of the various products derived from the same layer, and to explain the differences that occur in the relative proportion of their elements and in their mineral characters.

Atomic Relations of the Elements in the Rocks of the Siliceous Group.—I have investigated the atomic proportions between the silica and bases in the Magmas whose solidification has produced the pyrogenic rocks. They are represented in the following Table III. for the rocks of the siliceous group :—

TABLE III.

Proportions of Oxygen in Igneous Rocks of the Siliceous Group.	Granite.	Eurite.	Petrosilex.	Trachyte.	Trachytic Lava.	Phonolith.	Trachytic Porphyry.	Pitchstone.	Perlite.	Obsidian.	Pumice.	Syenitic Granite.	Andesite	Syenite.	Trachydolerite.	Retinite.	Ferriferous Pumice.
Ratio of Alumina to the other bases,	3.57	3.45	4.67	2.94	2.37	2.82	2.71	4.83	3.70	2.52	2.41	2.30	1.93	2.06	1.87	1.00	1.98
Ratio of Silica to all bases (except iron),	4.15	4.37	4.82	3.25	2.70	2.30	4.39	4.34	5.00	4.10	3.87	3.65	3.18	3.02	2.52	4.43	3.43
Ratio of Silica to all bases (including iron),	3.96	4.07	4.28	3.04	2.48	2.16	4.18	4.02	4.66	3.71	3.54	3.37	2.78	2.59	2.20	3.79	2.90

Relation of Silica to the Bases.—We see that in all these rocks, with the exception of trachytic lava and phonolith, the ratio between the quantities of oxygen of the silica and that of the alkaline and earthy bases is greater than 3; that is to say, there is more silica present than would be necessary to form tersilicates. This atomic proportion would also be generally higher than 3, if we supposed the oxide of iron to form an integral part of the silicates, which is not usually the case. It should be remarked, moreover, that the micas, which form an integral part of the rocks of the siliceous group, are very far from containing 3 atoms of silica for 1 of base. Thus when, in solidifying, the Magma resolved itself into an entirely crystalline mass, the silica, which is generally in excess, became free in the form of quartz.

Atomic proportion of Alumina to the other Bases.—Let us now consider the proportions of the different bases. In granite the proportion of the oxygen of the alumina to that of the other bases is 3.57 : 1. This is somewhat more alumina than would be requisite if the whole took the form of a felspathic mineral; for in all those minerals the characteristic oxygen ratio of R_2O_3 to RO is 3 : 1; the excess of alumina has gone to form mica, and oftentimes also accessory minerals, such as garnet, pinite, tourmaline, emerald, topaz, corundum, spinelle, &c. &c. In the normal granite, whose composition I have given, there is about 35 per cent. of quartz, 40 to 60 of felspar, which absorbs 8 or 10 per cent. of the alumina, or three-fifths; the remaining two-fifths go to the formation of mica and of the accessory minerals in the proportion of 20 to 25 per cent.

Explanation of Mineralogical Variations in Granites.—It is easy to see that the same Magma, in solidifying, might, according to circumstances, take the form of a granite, sometimes richer in felspathic components (orthose, with oligoclase or albite), and sometimes richer in quartz and mica.

It is to be remembered that there are two types of mica,—*one* ferro-magnesiferous, uniaxial, containing 11 to 16 per cent. of alumina; the *other* potassiferous, biaxial, containing double the quantity of alumina.

The latter mica crystallized out in preference to the other, when there was present in the Magma abundance of potash and alumina, and iron mostly in the state of peroxide: thence resulted the granites with a white silvery mica. But when there was present in the Magma a certain quantity of magnesia and protoxide of iron, the uniaxial mica, of dark tint, was produced, sometimes alone, but more commonly accompanied by the white mica. I shall presently explain how it came to pass that, at the close of the second period, these latter micas occurred exclusively, as has been shown by the examination of igneous rocks, geologically modern. When the oxygen of the alumina contained in granite formed nearly three

times the oxygen of the protoxides, very little mica was formed, and the Magma resolved itself into a pegmatite more or less rich in felspar.

Relation of Petrosilex to Granite.—In a former memoir ("Comptes Rendus de l'Académie des Sciences," tom. xx., p. 1277), I have shown that petrosilex is only a variety of granite, the compact state in which it occurs being due chiefly to the rapidity of its cooling; moreover, its composition differs generally from that of the granites proper by its containing more silica, less alkalies, and more alumina, as compared with the protoxide bases. Similar chemical characters are found in other *aphanic* rocks (compact or vitreous), such as pitchstone, retinite, perlite, &c., which are also very rich in silica, and relatively poor in alkalies, especially potash. I am thus led to regard these two circumstances as unfavourable to crystallization, and especially the too high percentage of silica, whose influence is, doubtless, connected with the property of passing into the viscous state on solidifying. In my first Memoir, published twelve years ago, I have made the remark that, if certain physical circumstances, and particularly the rapidity of cooling, have hindered petrosilex and eurite from assuming the crystalline state like a granite, a share of influence must also be attributed to certain differences in the chemical composition of the Magmas, especially to the great richness in silica and relative poverty in alkalies of the petrosiliceous masses. Thus my present researches have resulted in giving to this observation a greater character of generality.

Development of the Mineral Elements in Trachyte.—Let us now pass to the felspathic rocks of the tertiary, quaternary, and present epochs. My Table III. shows that in these rocks, with the exception of retinite and perlite, the oxygen of the alumina, compared with that of the protoxide bases, is a little less than 3 : 1. There is, therefore, somewhat less alumina than would be requisite to convert the whole mass into felspar; consequently, either a portion of the Magma remains in the state of a paste, or minerals less aluminous than felspar are developed; but these cannot be the white biaxial micas, for they contain still more alumina than felspar. Thus we do not find these micas in the felspathic rocks posterior to the secondary epoch; but we find in them the ferromagnesiferous micas uniaxial and dark-coloured, containing only from 11 to 15 per cent. of alumina. Even when the quantity of this base is small, silicates are formed, of whose composition it is not a necessary part, such as amphibole and pyroxene. We thus see how these minerals, which seem peculiar to the rocks derived from the basic Magma, come to be developed in an accessory manner in the trachytic Magma, by virtue of the insufficiency of the atomic proportion of alumina.

It is by the examination—not of the absolute quantities, but of

the atomic proportions of the various elements—that we arrive at those consequences which explain so simply the development of some minerals in preference to others in the interior of the igneous Magmas. The trachytes, for example, contain more alumina per cent. than the granites, and yet they present a less atomic proportion of this base, compared with the other oxides. From this chiefly arises the difference in the minerals associated with felspar in the two groups of siliceous rocks, the ancient and the modern.

Relations of Trachytic Porphyry and Phonolith to Trachyte.—I have still to explain how the trachytes which present an atomic proportion of silica to bases of about 3 : 1 can be connected, on the one hand, with masses whose richness in silica exceeds the ratio of 4 : 1, such as the trachytic porphyries, the retinites, &c.; and, on the other hand, with the phonoliths, which present ratios between 2 and 2.3 : 1.

In his admirable work on Volcanic Rocks M. Abich has considered phonoliths as trachytes modified by contact with sea water, on account of their richness in soda and their percentage of water. This view is correct, but appears to me to be insufficient: it does not explain, in fact, the high proportion of alumina in the phonoliths, on an average from 20 to 21 per cent., and which occasionally rises to 24 per cent., although the addition of the soda and water to the trachytic Magma ought to diminish rather than increase the relative proportion of this base. But we may observe that alumina, which is found in excess in the phonoliths, is found in defect in trachytic porphyry and in perlite, which is related to the former as a vitrefied product. These rocks contain only 10 to 14 per cent. of alumina, and it is the reverse with respect to silica, of which there are only 57 to 58 per cent. in phonolith, whilst there are 72 to 74 per cent. in perlite and trachytic porphyry. In consequence of these opposite relations, if we add equal parts of phonolith and perlite together, we have a mixture which presents nearly the composition of normal trachyte, excepting a certain excess of soda and of water produced by the addition of foreign elements.

It is, therefore, probable that phonolith and trachytic porphyry are only the two opposite products of a *liquation* which took place in the midst of the fluid mass: they are, as it were, the two inverse alloys into which we so often see a metallic bath divide itself.

Origin of Syenitic Granite and Andesite.—I explain in a similar manner the formation of two other species of rocks which occupy similar positions,—the one in the ancient siliceous rocks, and the other in the modern siliceous rocks,—viz., *syenitic granite* and *andesite*, a trachytic rock deriving its name from the chain of the Andes. These rocks are the degradations which form a passage

between the siliceous and the hybrid rocks, and which, by way of *liquation*, are derived from the one or the other system,—from the siliceous rocks, by a slight diminution in potash and silica, accompanied by an increase of alkalino-earthy bases; or from the hybrid rocks by an inverse change. In a preceding Memoir ("Comptes Rendus de l'Académie," tom. xxiii., p. 958), I have already noticed degradations of this kind, presented by the zirconian syenite of the south of Norway; also, in the Vosges, M. Delesse has seen the syenitic granite forming the centre of the ballon d'Alsace and other masses, degraded at its periphery, so as to present the characters of syenite, and pass even into diorite.

Effects of the same kind are shown by modern igneous rocks; thus, M. Abich found only 64 per cent.* of silica in the andesite which forms the mass of Cotopaxi, but he recognised 64 per cent.* in the rock which forms the crater. On the other hand, M. Ch. Deville has shown that at the sulphur mine of Guadaloupe and at Teneriffe the volcanic products which occupy the higher levels are more rich in silica than those of the lower levels. Thus, the phenomena of *liquation*, noticed by various observers, are not simple hypotheses, but ought rather to be admitted as facts; and they must have taken place below the crust of the earth, and in pouches or crevices of this crust, as well as at its surface. Moreover, these phenomena have natural limits, and, notwithstanding the apparent connexions which they establish between the two petrological series, there exists, nevertheless, a well-marked separation between the types of the siliceous and ferrocalciferous groups of rocks.

Atomic Relations of the Rocks of the Basic Magma.—Let us now state the relations which connect the various rocks of the basic group, and seek the causes which have produced their differences of chemical and mineral composition. The following Table gives the atomic proportions of the elements contained in the rocks derived from the basic ferrocalciferous layer:—

* There is some error in these numbers.—TRANSLATOR.

TABLE IV.

Proportions of Oxygen of Rocks of the Basic Layer.	Diorite.	Melaphyre.	Hyperite.	Euphotide.	Basalt.	Dolerite.	Pyroxenic Rock of average composition.	Dolerite Lava.	Leucito-Augito-Sodiferous Lava.	Serpentine.
Atomic Proportion of Alumina to the other bases,	1.53	2.21	1.08	0.98	1.01	1.11	1.36	1.26	1.26	
Atomic Proportion of Silica to all bases, excepting iron.	2.24	1.85	2.06	1.80	1.94	2.12	1.96	2.00	1.91	1.39
Atomic Proportion of Silica to all bases,	1.78	1.63	1.67	1.53	1.57	1.62	1.61	1.60	1.67	1.33

Atomic proportion of Silica twice less than in the Rocks of the Siliceous Magma.—Of all these rocks, diorite is the only one in which the atomic relation of silica to all the bases is much greater than 2 : 1; moreover, if we take account of the oxide of iron, which is an essential constituent of hornblendic amphibole, pyroxenic augite, &c., we see that, in the basic rocks, the oxygen of the silica is generally comprised between 1.50 : 1 and 1.75 : 1 for all bases; thus, this ratio is nearly twice less than in the rocks of the siliceous group; and we thus see how great a difference separates the eruptive products of the two fluid layers, when we compare them with reference to the atomic proportion of their elements.

General Absence of Orthoclase and Albite in the Basic Rocks.—As the ferrocalciferous mineral associated with the felspathic element in the basic rocks is usually a bisilicate (pyroxene, hypersthene, diallage), or the union of 3 atoms of bisilicate with 1 atom of trisilicate (amphibole), it is plain that there is not silica enough left for the bases forming the felspar to combine as trisilicates; from this results the rarity of orthoclase or albite in the basic rocks; it is only in varieties of diorite rich in silica and approaching syenite, that we meet with trisilicates, and even then it is rather oligoclase that is met with. If, even in these diorites, felspars have been formed as rich in silica as oligoclase, notwithstanding the small atomic proportion of silica in the Magma, this arises, in most cases, from the fact that there was produced at the same time, as if by a sort of liquation, ferromagnesiferous mica, garnet, and often epidote, minerals which are all protosilicates, and which must have left disposable a certain amount of silica: this may even have been sometimes sufficient to have become isolated, as quartz, although the atomic proportion of silica to the bases was far below the ratio of 3 : 1. Moreover, diorite does not always contain oligoclase; we often find in it also, as M. Delesse has observed, andesine, which is a bisilicate, or sometimes even labradorite.

Felspathic Elements of the Basic Rocks.—In the basic group, the amphibolic rocks alone contain felspars somewhat rich in silica, such as oligoclase; the other rocks, which have pyroxene, hypersthene, or diallage, for their ferrocalciferous element, contain, as felspars, compounds in which the alumina is always in the state of protosilicate, and in which the protoxide bases are in the state, sometimes of trisilicate (labradorite), sometimes of bisilicate (Vosges felspar of M. Delesse), and sometimes of protosilicate (anorthite and saussurite).

Sometimes the felspathic element is found replaced, either wholly or in part, by alumino-alkaliferous silicates, which have an atomic composition analogous to that of felspar, but very different crystalline forms: thus, augite is sometimes associated, in the leucitic lavas, with amphigene, which has the atomic for-

mula of andesine; in the nephelinic dolorites, with nepheline, representing anorthite; in the basalts, with zeolitic minerals, which, as M. Ch. Deville* has remarked, may be considered as hydrated felspars.

Relative Proportions of Alumina and other Bases.—If we consider the atomic proportion of alumina and of the alkaline and alkalino-earthy bases, we see that in the basic rocks this ratio varies from 1.5 to 1; and since in all the felspars there are 3 atoms of oxygen in the alumina for 1 in the other bases, we see that the formation of the felspathic element has absorbed, together with all, or nearly all, the alumina, from $\frac{1}{3}$ to $\frac{1}{2}$ of the other bases; the alkalies, as well as a portion of the lime and magnesia, have gone to form the felspars; the remaining portion of these bases has served to form the ferrocalciferous and magnesiferous bisilicate.

To the other characters which I have already noticed as belonging to the rocks of the basic group, a new one must be added, viz., that the atomic proportion of alumina, relatively to the other bases, is generally twice less than in the rocks of the acid group; and consequently, the minerals which accompany the felspathic element (amphibole, pyroxene, diallage, &c.) do not contain, in general, alumina as an essential ingredient; yet in the diorites mica is often present; but it is the ferromagnesiferous mica, which is twice less aluminous than the white mica, and moreover is formed in this situation at the expense of the felspathic elements.

General Magnetic Attraction in the Basic Rocks.—I add that the various bases having entered into the combinations which have produced the felspathic, amphibolic, and pyroxenic minerals, there has usually remained an excess of oxide of iron, which has separated itself under the form of saline oxide (magnetic oxide), sometimes accompanied by titaniferous iron: thus nearly all these rocks attract the magnetized needle.

Relation between Melaphyre, Basalt, and Dolerite.—There are also produced, in the formation of the basic rocks, phenomena of liquation analogous to those which I have noticed in treating of the siliceous rocks: in fact, the melaphyres are masses very rich in alumina, containing generally from 18 to 25 per cent., whilst in other basic rocks there are rarely more than 16 per cent. But if, on the one hand, the melaphyres are so strongly aluminous, there are, on the other hand, pyroxenic rocks relatively poor in alumina, such as basalts, certain dolerites, and diallagic rocks; there are even basic rocks containing only a minimum of this base, such as the serpentines and masses of pyroxenic nature, such as lherzolite. But there is no difficulty in admitting that the phenomena of liquation have divided the basic fluid into two alloys,

* As well as all other mineralogists.—TRANSLATOR.

of which one, strongly aluminous, formed the melaphyres, whilst the other engendered masses of rock containing a greater or less quantity of ferrocalciferous and magnesiferous silicates.

Development of Zeolites in place of the Felspathic Element.—In solidifying, certain basic rocks, as basalt, have retained water, a circumstance which has given rise to the formation of the aluminiferous hydrosilicates of the family of zeolites, replacing in part the felspathic element (labradorite). These hydrosilicates are accompanied, not only by augite and magnetic oxide, but often also by peridote or ferromagnesiferous protosilicate.

Leucito-Augitic Lavas.—In my Table of the composition of the basic rocks I have introduced the lavas called leucito-augito-sodiferous, and which are dolerites or melaphyres, whose labradorite is replaced by amphigene with soda base. We may cite, as examples, the present lavas of Vesuvius. In a chemical point of view they differ little from doleritic lavas (composed of labradorite and pyroxene), except by a less proportion of oxide of iron, and by the abundance of soda, which appears due to the intervention of sea water.

Development of Garnets in Igneous Rocks.—There is another mineral which is not generally considered as forming an essential part of igneous rocks, but which is often found in them in great abundance, and with a certain regularity; it is garnet, which has for formula

$$3\,(CaO,\ MgO,\ FeO,\ MnO)\ SiO_3 + (Al_2O_3,\ Fe_2O_3)\ SiO_3.$$

In consequence of its relative poverty in silica, and its richness in alkalino-earthy bases and oxide of iron, garnet ought to be less abundant in the siliceous rocks than in the hybrid rocks, such as syenite, or certain basic rocks; and it is, in fact, so abundant in the amphibolic rocks, that geologists have believed they ought to form a new species of this rock, under the name eklogite. But, like the leucite of some lavas, or the nepheline of some dolerites, the garnet takes its origin at the expense of the felspathic element, for in its formation it has absorbed a great quantity of alumina. The same mineral is found also frequently associated with serpentine, where it appears to supply, to some extent, the want of felspathic elements.

General principle of Explanation of the Differences of Chemical Composition and Mineralogical Character of Rocks.—To sum up:—If we generalize the principle of the phenomena of liquefaction which tend to exhibit themselves in every mass in the state of igneous fusion, and composed of elements of different natures; if we take account of the facts established by geological observation and by chemical analysis, as well as of the phenomena which are produced under our eyes in foundries, we can explain, in a simple and natural manner, the inequalities in chemical composition of

the rocks derived from the same fluid mass; if, moreover, we have regard to the atomic proportions of the various elements of each Magma, we can render an excellent account of the mineralogical differences in the rocks arising from them, and we may even predict what minerals ought to occur in the crystallization of given silicated masses.

The special physiognomy of modern Eruptive Rocks due principally to the influence of elastic gases.—I should add, that there is a special cause which powerfully contributes to give to modern eruptive products a special physiognomy, and also to enlarge the limits within which their chemical composition varies, especially in the case of elements capable of forming volatile compounds; this cause is, in addition to variations of pressure, the intervention of external elements, especially of gases and vapours, which manifest their influence in the modern igneous products much more decidedly than in the ancient. This is the action that gives to rocks geologically modern their amygdaloidal texture, that renders them oftentimes scoriaceous and pumiceous; it likewise modifies the form of the orifices of eruption, which assume the condition of craters placed on the summits of conical mountains.

Results that justify the division of the Igneous Rocks into two groups derived from different Magmas.—The investigations that I have just explained have brought out relations, physical, chemical, and geological, which connect together the pyrogenous rocks, so varied in their outward appearance; and the clearness with which these relations have become disclosed seems to me to confirm the proposition that I laid down at first, viz., that all the igneous rocks are derived from two fluid layers situated below the earth's solid crust, and of which the one is characterized by its richness in silica; and the other, poorer in silica and alkalies, contains an incomparably larger proportion of alkalino-earthy bases, and of oxide of iron, whilst it is also distinguished by very different atomic proportions. Moreover, the products of the first layer contain almost always, as an essential and predominant element, the only species of felspar which crystallizes in the monoclinic system, while the various species of felspars which form integral portions of the products of the second layer belong, without exception, to the triclinic crystalline system. The distinction which I have established is found thus confirmed, even in a crystallographic point of view; but it remains for me to verify whether it is in harmony with geological observations, and whether it permits us to render account of the successive eruption of the pyrogenous rocks of different ages.

PART IV.—EXAMINATION OF THE FACTS RELATING TO THE EMISSION OF THE IGNEOUS ROCKS.

The Igneous Rocks of the First Ages belong almost exclusively to the Siliceous Group.—The first pellicle that solidified on the surface of the yet incandescent globe was evidently formed by the uppermost layer, the lightest and most fusible; thence resulted the primitive granite. If we now examine the formation of the first ages, viz., the azoic slaty beds, the palæozoic rocks, and the lower secondary formations, we shall find that the pyrogenous rocks, which during those ancient periods rose to the surface of the globe, and which have covered a large portion of it, are composed almost exclusively of felspathic and siliceous rocks derived from the upper Magma, viz., granites, eurites, felspathic and quartziferous porphyries, and their derivatives. In fact, a single glance of the eye at a geological map of Europe, shows that up to the Jurassic period the amphibolico-pyroxenic rocks, arising from the basic Magma, form rarely more than one hundredth part of the space occupied by the siliceous rocks; they occur, in fact, only accidentally, as compared with these.

The eruption of the ancient Basic Rocks results from secondary and consecutive phenomena.—It is a general fact, as I have observed, in all the crystalline regions I have visited in the north of Europe, in Germany, in the Vosges, the Alps, the Pyrenees, and the west of France, that the emission of the basic rocks was constantly preceded by eruptions of granitic or euritic rocks, across which rocks we see them form veins, sometimes in great quantity. These subsequent eruptions belong, so to speak, to secondary and consecutive phenomena; and it is also remarkable to observe the amphibolic rocks concentrated, for the most part, in the zone occupied by the granitic rocks, or along the borders of that zone.

Origin of the general arrangement of Dioritic Rocks in dykes and masses traversing the Granitic Formations and the adjacent Beds.—Let us consider whether these facts are not in accordance with the consequences of my researches. In consequence of dislocations produced in certain parts of the earth's crust, the upper portion of the fused mass rises through the openings by virtue of the compression it experiences from the adjacent masses and the expansive power of elastic gases—thus are produced the great eruptions that bring to light the granitic Magma. But this ejection cannot take place without changing the conditions of equilibrium of the basic Magma situated below; a certain portion of it is in general drawn in, after the siliceous Magma, into the hollows and crevices of the terrestrial crust, where it preserves in part its heat and fluidity during the cooling of the great felspathic masses accumulated around the slits or orifices of eruption; these siliceous masses

giving origin to chains of mountains, or hills of rounded contour, respectively. In solidifying, the granitic masses became contracted and fissured, and various causes of dislocation produced at the same time, in the adjacent stratified rocks, fissures or slits, through which were injected the still liquid portions of the basic Magma displaced in consequence of the eruption of the granite. Such appears to be the origin of the dykes, and more or less considerable masses of diorite, which we see piercing the granitic formations and their surrounding rocks.

Lodes and Stockworks of Granite and Pegmatite.—Moreover, the interior portions of the siliceous Magma, not yet consolidated, gave rise to analogous effects, and produced those lodes and stockworks of granite and pegmatite which have been remarked in most granitic regions, and which are distinguished from the surrounding mass by certain characters of composition or of texture.*

Succession of the various Phenomena.—The same series of phenomena must have been produced at different periods, sometimes in the same country, as I have observed in the north of Europe. Thus we see that a region where a great eruption has once taken place becomes the scene of secondary and successive eruptions, as volcanic phenomena prove to us at present, though on a different scale. Long after the emission of the stony products, the disengagement of gases and vapours continues, from which result metalliferous veins, and we must refer to the same source the emanations from thermo-mineral springs, which may be regarded as the last manifestation of igneous phenomena.

Change in the Mode of Eruption of the Basic Rocks during the second half of the Secondary Period.—Whatever be the reason, it is certain that the basic rocks, whose eruption took place during the primary geological periods, were formed merely by accident, as compared with the immense development of the siliceous and felspathic masses. It was during the second half of the secondary period that well-marked changes occurred in the nature of the rocks that rose through the terrestrial crust; when the upper layer of the fluid sheet had in general been much diminished in thickness, either in consequence of the eruptions, or of the solidification resulting from the radiation of heat into space. From this time forward, the substance of the lower layer, rich in earthy bases and oxide of iron, began to produce great eruptions, raising itself directly and in great masses from the central liquid zone; it possessed a degree of heat and liquidity much greater than at the former epochs, in which it formed only secondary and consecutive eruptions. Thus it was not limited to veins or masses of mode-

* According to our experience, the difference is in texture alone and not in chemical composition, which appears to be the same as that of the main body. —TRANSLATOR.

rate dimensions, but was spread over the bottom of the seas, or the surface of the land, forming vast sheets of trap and basalt.

Eruptions subsequent to the Secondary Period.—It is further remarkable to observe, how in the modern epochs, as in the ancient, at places where the siliceous crust was still thick enough to give rise to considerable emissions, these eruptions have preceded those of the basic Magma. Thus, in Auvergne, and on the Rhine, during the tertiary period, the outpouring of basalts succeeded large eruptions of trachytic rocks. Likewise, before the creation of man, a considerable extent of the surface of Italy was covered by trachytic products, though at present the eruptions of Etna and Vesuvius bring to light the products of the lower ferrocalciferous layer; for these products have pyroxene as their chief constituent. This is not, however, universally the case over the globe, since the volcanoes of Iceland and of the Andes emit, generally, trachytic products, though poorer in silica and richer in earthy bases and oxide of iron than the ancient trachytes; as, indeed, ought to be the case, since the siliceous layer, from which these felspathic masses proceed, is at present almost completely exhausted, and ought to tend to merge in the basic layer, by the action of the elastic gases: we shall see also, further on, that many of the products of existing volcanoes are the result of the re-melting of matters ejected at anterior epochs.

Connexion between the ancient and modern Eruptive Phenomena.—I have just distinguished, in the eruptions of the ancient igneous rocks, two kinds:—

1st. *Eruptions of the first order*, arising directly from the fluid layers on which the earth's crust reposes.

2nd. *Eruptions of the second order*, or consecutive, having, as foci, masses of incandescent matter, which, instead of expanding outwards, have remained caught up in the interior of the crust.

The observation of the igneous phenomena of the later geological periods (tertiary, quaternary, and recent) seems to me to furnish a happy confirmation of this idea, and induces me to clear up the connexion that exists between earthquakes, volcanic phenomena, and the formation of chains of mountains.

General communication of Volcanic Chimneys with the secondary Foci.—If we consider the independence of action of volcanoes, even the most contiguous, and the extreme variability in the intensity of the eruptions, either of different volcanoes compared together, or of the same volcano observed at different epochs; if, moreover, we observe the extent of the zone affected by the eruptive action of each volcano; and, finally, if we take account of the very small quantity of matter emitted in most eruptions—we recognise very speedily a want of proportion between such *minimum* results and the colossal power of a cause which could raise the liquid central mass from a depth of four or five myriameters. It

is, therefore, probable that, in their ordinary state of activity, the volcanic chimneys do not communicate directly with the great incandescent layer, but that they are simply fed by the secondary foci, or pockets (as it were), of incandescent matter, which are situated at various depths below the surface.

Profound difference between Volcanic Phenomena and the Causes that produced the Chains of Mountains and Chains of Volcanoes.—Thus, the eruptive effects which take place at the mouths of volcanoes, either at intervals of time, or in a continuous manner, as at Stromboli, are merely local effects, of a secondary order, and completely distinct, both by their essential character and in the seat of their immediate cause, from those violent cataclysms which have given rise to chains of mountains, or to great lines of volcanoes. Hitherto the history of the human race has not recorded any of those grand phenomena that result from great ruptures, traversing the entire thickness of the terrestrial crust, and prolonged for considerable lengths; yet it is in these cases only that sufficiently great masses of incandescent matter have risen from the bosom of the fluid zone, to form important ridges on the surface of the globe.

Consecutive Phenomena of the great Ruptures of the Crust of the Globe.—On these great lines of fracture are situated, here and there, volcanoes arranged in chains; but the chinks penetrating downwards to the liquid internal zone are promptly obliterated throughout the greater part of their extent, and many volcanoes become extinct which have had only an ephemeral existence, as, for example, most of the ancient volcanoes of the interior of France; others have preserved a certain degree of activity, being fed by masses of matter contained in cavities of the terrestrial crust; others, again, of these volcanic foci appear to "revictual" themselves, from time to time, by chimneys penetrating more deeply, and representing portions of the primitive fissures, only half closed, and susceptible of being reopened by violent commotions.

Extraordinary Eruptions estimated by the enormous quantity of Lava ejected.—It is probably at these epochs of reopening of the deep fissures that certain extraordinary eruptions occur; such as that of Etna in 1669, which produced a volume of lava calculated at upwards of 600,000,000 of cubic meters; and that of Hecla in 1798, which poured out over Iceland a torrent of lava 80 kilometers long, by 15–16 kilometers broad. These extraordinary eruptions, however, are altogether exceptional, and represent what we may call the *crises*, or *acute periods* of volcanoes.

Incorporation in the Secondary Foci of Superficial Deposits.—The examination of the products emitted during ordinary eruptions shows that, instead of consisting of substances proceeding directly from the central fluid layer, they are composed, in part, of materials more or less belonging to the surface, and which have become

ingulfed or incorporated in the secondary foci. Many lavas are the result of the remelting of older lavas; thus, the amphigenic products emitted by Vesuvius in our day appear to be only the "*rechauffée*" of the lavas of Somma, with the addition of soda; in like manner, the material of the lava stream of the Arso, in 1301, is trachytic, and of the same nature as the more ancient volcanic mass that produced the Isle of Ischia; also, according to the analyses of M. Abich, the eruptive mass of Monte Nuovo is no other than the piperino of the Flegrean fields remolten.

Intervention of exterior Elements producing successively opposite Phenomena.—In this state of secondary or consecutive activity is manifested, in its highest degree, the intervention of external elements, belonging to the ground, surface water, and the atmosphere: often, in fact, deposits loaded with organic bodies have been ingulfed, and the introduction of sea water determines that enormous increase in soda which has been remarked in certain lavas, at the same time that it supplies the disengagement of elastic fluids, the influence of which is then preponderant. Such appears to be, in fact, the source of the principal elements of gaseous emanations, aqueous vapour, and the hydrogen which enters into combination with the chlorine and sulphur arising from the reduction of chlorides and sulphates, which reduction takes place by the contact of organic matter, or of bodies imperfectly oxidated, in the interior of the subterranean foci. But, by an opposite phenomenon, during their ascensional movement towards the surface, a part of the emanations, especially the hydro-sulphuric acid, undergoes a combustion by the entrance of the oxygen of the air, drawn in through the fissures of the volcanic cones, as the recent analyses of M. Ch. Deville have established.

Change of burning Volcanoes into Solfataras.—When, in a subterranean focus, the heat becomes too weak to maintain the mineral masses in a state of fusion, the chimney that served for its excretory duct loses the characters of the burning volcano, and becomes changed into the solfatara, and returns to its former state only in the rare cases in which the focus is again placed in communication either with the central liquid mass, or with other foci situated in the neighbourhood.

General Characters of Earthquakes compared with Volcanic Effects.—If we now examine earthquakes, we shall recognise in them characters totally different from those of volcanic phenomena. They give rise to no effect, either calorific or chemical; and, deducting the tremblings or shocks evidently connected with volcanic foci, the great earthquakes are distinguished by the vast extent of the zones shaken, which generally lie in particular directions. This property of linear and almost indefinite extension, directly opposed to the radiating and circumscribed action of volcanoes, shows that the two classes of phenomena have a diffe-

rent seat. When we observe that earthquakes are felt almost simultaneously at places distant from each other hundreds of leagues, we cannot doubt but that the seat of their action is situated below the terrestrial crust. The effects which we experience result from the transmission of disturbances imparted to the inner surface of this crust, at its contact with the incandescent liquid layer, whose surface is subject to various actions, physical and chemical: the elastic fluids, also, collected in this zone, appear to play an important part in those commotions.

Relations of Earthquakes to the Volcanic Zones.—Earthquakes are, in general, independent of active volcanoes, although they may react upon them, and even provoke eruptions. Those regions which are violently affected by shocks are related to the chief mountain chains, and especially to the great volcanic zones, which represent the most recent lines of deep fractures, and it is evidently in the direction of these lines that their effects are most marked; in other respects they present variable characters, according to the nature, structure, and mode of superposition of the compartments of the exterior envelope.

Principal causes of difference in the mode of action of Earthquakes and Volcanoes.—The chief difference between earthquakes and volcanic phenomena consists in this, that the former have their seat, in general, beneath the crust of the globe, while the latter have their foci immediately below this crust, and consequently at much less depths, which renders more easy the opening and conservation of chimneys of communication with the exterior. Thence results the dissimilitude in their mode of action; the effects of earthquakes are almost exclusively mechanical, whilst, by virtue of the proximity of their foci, the manifestations of volcanoes are distinguished principally by calorific and chemical phenomena, in which the intervention of exterior elements, and especially of surface water, appears to play an important part.

The formation of mountain chains cannot be attributed to Earthquakes.—However injurious they may be to man, earthquakes can give rise to fissures of only small extent, both in length and depth, and their indefinite repetition could not produce any of the great wrinkles that furrow the surface of the globe. The formation of chains of mountains, or of volcanoes, is, in fact, the consequence of ruptures effected in the entire thickness of the terrestrial crust; that is, across a depth of solid matter not less than 40 kilometers.* Such fractures evidently require the action of forces infinitely more powerful, the gradual development of which, according to M Elie de Beaumont, appears due to the increasing excess in volume of the periphery of the globe relative to the internal mass, which

* That is to say, 25 miles. We do not know why M. Durocher fixes on 25 miles, as 2500 appear to be equally entitled to consideration.—TRANSLATOR.

contracted more and more, in proportion as the cooling was extended to greater depths.

General Résumé.—Thus, the results which I have deduced from my researches, far from being at variance with geological observations, furnish a simple and natural explanation of the phenomena relating to the emission of igneous rocks; and clear up the relations which connect volcanic action and earthquakes with the formation of mountain chains. Thus we have seen revealed the mutual relations of the most varied igneous rocks, which form the branches (as it were) diverging from two distinct trunks; by resting on the laws and acknowledged facts of science, I have been enabled to render account of the inequalities that occur in their chemical composition, and of the variations observable in their mineralogical characters. In place of that complex entanglement of igneous rocks which we see represented in the tables of those learned geologists who have been pleased to figure the structure of the interior of the globe, we have only to conceive, inside the crust, a fluid zone presenting two distinct layers, and from which have proceeded, in succession, all the rocks which have been spread out over the surface, and which, having experienced the effects of *liquation*, more or less decided, have put on various forms, according to their conditions of cooling, and also according to the unequal action of gases and vapours, an action which manifests itself more decidedly in the more modern products. I might have further cited, as a new confirmation of the results of this memoir, the transitions observed for a long time in many countries between the various rocks of the same Magma, such as the passage of granite into quartziferous porphyry, eurite, and petrosilex, and their connexion with trachytic rocks; or, on the other hand, the passage of the amphibolic into the pyroxenic and diallagic rocks; but I have already treated of these facts in my preceding works.

PART V.—NATURAL CLASSIFICATION OF IGNEOUS ROCKS.

Classification of Igneous Rocks in three series.—If all the igneous rocks were derived from two Magmas, each of which has given rise to emissions from the time that it formed a first solid crust to the globe, it is plain that the classification of these rocks cannot be made according to one scale, but rather according to two great parallel series, each of which corresponds to one of the Magmas: moreover, there should be formed an intermediate series for the hybrid rocks. We are thus conducted logically to the classification exhibited by the following Table, V., which appears to me to reconcile the three sorts of analogies existing among the igneous rocks, viz., the chemical, the mineralogical, and the geological.

	itic and compact ditto.	(5.) Porphyritic and Trappean Euphotide, and Hyperite Variolith, or compact Euphotide, Serpentine.
	of the secondary epoch. Porphyry, passing into c Porphyry and Mela-	(6.) Diorite, Ophite, and rocks with Uralite base, Doleritic Trap. (7.) Ophitic Porphyry, Melaphyre, sub-compact Trap.
III. NEO ROC	s of Trachyte, rich in ibole and Pyroxene hydolerite of Abich). itic ditto. Perlite, Ferriferous Pitchstone.	(8.) Dolerite and Pyroxenic rocks in crystalline grains. (9.) Basanite, or Basaltic Porphyry, compact and vitreous Basalt.
	oleritic Lava, containassy Felspar, Pyroxene, phibole. tic, compact, or glassy Ferrocalciferous Ob- and Pumice.	(10.) Doleritic Lava, Leucito-Augitic Lava, Pyroxenic Lava. (11.) Porphyritic ditto, compact and glassy ditto.

APPENDIX (B).

ON THE ORIGIN OF GRANITE.

ALTHOUGH I have adopted in the text Durocher's theory of the Granitic and Trappean Magmas, yet I do not believe that any trace of these primitive Magmas is now to be found.

The granites of Finland, Sweden, Norway, Scotland, and Donegal, forming the Scandinavian system, are all stratified rocks, which have undergone a metamorphic action, but which originally existed as mud deposited by water. These are the oldest granites in Europe, and are proved to have been of aqueous origin. The Laurentian system of North America, in like manner, constituting the oldest rocks of that continent, was originally deposited from water, and subsequently underwent a metamorphosis, in which both heat and water had an equally important share.

But, although the oldest granites in Europe and America have been proved to have been originally deposited mechanically from water, and cannot therefore belong to the granite Magma of Durocher, the question as to how they acquired their present granitic character has not been satisfactorily settled; and the problem of the origin of granite is rendered still more perplexing by the fact that there are certainly granites, like those of Leinster and Cornwall, which in their primitive condition were of igneous and not of aqueous origin, and must have resembled in all respects the hypothetical granitic Magma of Durocher.

With respect to the igneous or aqueous origin of granite, geologists in recent times have almost unanimously advocated the igneous theory, and chemists the aqueous theory.

The evidence of the geologists has been collected in the field; and though it is wanting in the scientific precision which the chemists have called to their aid, yet it possesses a force which all the arguments on the other side have as yet failed to oppose. The evidence in favour of the igneous origin of granite is essentially physical, and is founded on the observation, in the field, of the manner in which granite is found to penetrate, in minute veins, every rock older than itself with which it comes in contact. It

appears to me that no pasty condition of granite, such as that imagined by Delesse, and that no aqueous solution of granite, such as Werner supposed, can account for the remarkable group of physical facts which geologists have collected on this subject since the days of Hutton; and that we must admit that when granite penetrated the schists and limestones beside it, in small veins, it must have had a liquidity greater, perhaps, than that of any lava with which we are acquainted, except, probably, the siliceous lava of the Sandwich Islands. On the other hand, the arguments derived from chemistry appear to me equally unanswerable, in showing that water was present in abundance during the formation of granite, and that in some cases it is even to be regarded almost in the light of a chemical precipitate from an aqueous solution.

Before attempting to reconcile these opposite views, let us consider for a moment the arguments of the chemists. They are as follow:—

I. The specific gravity of the quartz that occurs in granite is known to be 2.6, which Count Schaffgotsch has proved to be the specific gravity of silica formed by aqueous solution; while the specific gravity of silica which has undergone igneous fusion is only 2.2.

II. Fuchs has shown that in granite we have several minerals —quartz, felspar, mica—whose points of fusion are very different; and yet they have not crystallized in the order of their infusibility, but in the inverse order, viz., of their fusibility; the most infusible of them all, quartz, having crystallized last, and acted the part of a mother-liquor to the others.

III. Professor Heinrich Rose observes that the presence of such minerals in granite as oligoclase, the micas, hornblende, &c., in presence of free silica, is inconsistent with the hypothesis of igneous fusion; as such fusion would convert these minerals into more highly silicated forms.

IV. Lastly, the actual presence of large quantities of water (4 per cent.) in margarodite mica, which forms an important constituent of the granites of Leinster and Donegal, and the occurrence of such minerals as allanite, gadolinite, &c., in the Norway granites, minerals which intumesce and change their properties on ignition, the presence of such minerals as these in granite appears to many chemists inconsistent with the theory of igneous fusion.

Of these arguments, I confess that the first and fourth alone appear to me to be weighty; and that the force of the second and third may be evaded by an appeal to our ignorance of the manner in which "liquation" may operate in determining the order and manner of crystallization of minerals forming on the

cooling of a mixed Magma, after igneous fusion. Indeed, with respect to the second argument, which requires quartz to crystallize first in granite, there are two cases in Ireland in which this condition has been fulfilled, by the separation of the quartz in the form of double hexagonal pyramids. These two cases are —the felspar porphyry of Forkhill, in the county of Armagh, and the granite of Slieve Corragh, in the county of Down. The porphyry of Forkhill would be pronounced by any geologist to be a metamorphic slate, and not a fused rock; and yet it fulfils Fuch's condition of igneous fusion, by the apparent order of crystallization of its constituent minerals.

The following analysis shows the composition of the Forkhill porphyry:—

Forkhill Porphyry.

	Percentage.
Silica,	76.00
Alumina,	8.72
Iron (peroxide),	5.33
Lime,	0.79
Magnesia,	0.11
Soda,	0.88
Potash,	7.82
Iron (protoxide),	0.15
Manganese (protoxide),	0.20
Water,	0.40
	100·40

Physical description of Forkhill Porphyry.

A felspathic quartziferous porphyry. Sp. gr. = 2.588.

Paste, greyish, or honey-yellow, of felstone texture, dull lustre.

Quartz crystals very perfect ($\frac{1}{8}$ in.), studded abundantly through the paste in six-sided prisms, and hexagonal dodecahedra.

Rare black specks, like hornblende, sometimes segregating themselves into lenticular masses.

The argument against the igneous origin of granite derived from the specific gravity of its quartz, appears to deserve much attention from the fact, that the difference of density observable in bodies crystallizing from aqueous and igneous fusion (the former exceeding the latter) appears to be universal, and attributable to the retention of latent heat by the substance exposed to igneous fusion.

Thus sulphur, as is well known, crystallized from its solution in chloride of sulphur or bisulphuret of carbon, has a specific gravity of 2.05; while the crystals formed from melted sulphur have

only a specific gravity of 1.98; and the third variety of sulphur, known as ductile sulphur, formed at a still higher temperature, has a still less specific gravity, being only 1.957.

But we need not have recourse to the analogies of chemistry to show the diminution in specific gravity which granite or quartz would undergo if fused.

M. Delesse has published* experiments on the specific gravity of various rocks in their natural and artificial fused or vitreous condition, from which I have calculated the following table:—

Table of Specific Gravities of Natural and Artificially Fused Rocks.

Name of Rock.	Specific Gravity of Natural Rock.	Specific Gravity of the Glass.	Difference.	Number of Specimens.
Euphotide,	2.9647	2.5310	0.4337	3
Granite, Quartz-porphyry,	2.6626	2.3913	0.2713	8
Porphyry,	2.6872	2.4400	0.2472	5
Granite Porphyry,	2.6510	2.4250	0.2260	1
Syenitic Granite,	2.6677	2.4500	0.2177	3
Diorite,	2.8593	2.6570	0.2023	3
Melaphyre,	2.7750	2.6040	0.1710	1
Trachyte,	2.7270	2.6170	0.1100	1
Basalt,	2.8524	2.7700	0.0824	5
Modern Lava,	2.5233	2.4919	0.0314	8

* Liebig and Kopp, Annual Reports, vol. ii., p. 457: 1847-8.

It appears to me that the column of differences in the preceding table greatly strengthens the argument of those chemists and geologists who believe that water played a much more important part in the formation of granites and traps than it has done in the production of trachytes, basalts, and lavas, and that they owe their relatively high specific gravity to its agency.

The only manner in which it seems possible to reconcile the opposite theories of the origin of granite, derived from physical and chemical arguments, is to admit for granite what may be called a hydrometamorphic origin, which is the converse of what is commonly called metamorphic action, but which might more properly be designated as pyrometamorphic action. The metamorphism of rocks might thus be assumed to be twofold: hydrometamorphism, by which rocks originally fused, and when in liquid fusion, poured into veins and dykes in pre-existing rocks, are subsequently altered in specific gravity and arrangement of minerals, by the action of water at temperatures which, though still high, would be quite inadequate to fuse the rock; and pyrometamorphism, by which rocks originally stratified by mechanical deposition from water come to be subsequently acted on by heat, and so transformed into what are commonly called the metamorphic rocks.

Granite, as I believe, although generally a hydrometamorphic rock, may occasionally be the result of pyrometamorphic action; and such appears to have been its origin in Donegal, in Norway, and perhaps in the chain of the Swiss Alps.

LECTURE II.

SANDSTONES, SCHISTS, AND LIMESTONES—OXYGEN IN SANDSTONES—WELSH ROOFING SLATE—CLASSIFICATION OF SANDSTONES—PASTE OF SANDSTONES—CLASSIFICATION OF SCHISTS AND LIMESTONES—ACCIDENTAL MINERALS.

I HAVE now to ask your attention to the stratified rocks—to their chemical composition—and their mechanical origin by deposition from water. The igneous rocks are distinguished from each other mainly by their chemical and mineral composition. We have no such varieties of physical causes in their origin to consider as we have in the stratified rocks, which are formed by water; as in the case of the latter, the stratified rocks, we shall find it necessary to take account of two principles of classification—namely, the chemical composition of the rocks, and their physical or mechanical origin.

The most convenient mode of classifying the aqueous, or stratified rocks, is to divide them into three great groups, according to their chemical composition; and then to subdivide these groups into minor divisions according to the different conditions, generally mechanical, under which they were deposited. We shall find that the chemical composition of the stratified rocks exerts a most important influence upon their mode of preserving fossils; that, according to the chemical composition of the fossil bone or shell, or the coral skeleton, and the chemical composition of the mud which

was the original condition of the rock in which it is found embedded, the appearances that fossils present in these different rocks vary greatly; and that we shall not be able to understand them without a consideration both of the chemical composition of the fossil and of the rock in which it is contained. On these grounds I give a preference to the chemical mode of classifying even the aqueous rocks, and divide them into three great groups of sandstones, schists, and limestones.

These rocks have very different origins; not only do they differ in their chemical composition, but even in the mechanical or physical conditions under which they are formed they constitute three distinct groups.

The sandstones, as a rule, are coarser in texture and structure than either the schists or the limestones; they were therefore formed by the action of ruder forces, and are generally supposed, and I believe correctly, to indicate a deposition from water in a state of greater agitation and in more rapid motion than the streams that deposited the muds which constitute our schists and limestones; they indicate, therefore, shallower water, and a coast line. As a rule it may be assumed, that the sandstones have not only a peculiar chemical composition, but are the result of deposition in shallow water. The schists and the limestones agree in one important particular with regard to their mechanical origin; they are both deposited in a state of extreme fineness, and in all probability far from land. We have every reason to believe that the finer the mud is, the further it will be carried out to sea by the currents, and therefore the deeper will be the water in which it is

deposited. This is peculiarly true of the rocks that we call schists. It is not quite so true of the rocks that we call limestones, because, although the limestone agrees with the schist in the extreme fineness of the particles of the mud to which it can be worn, yet it differs in this most important particular, that the schist owes its origin exclusively to mechanical action, the transport of the mud by the water, whereas the limestone owes its origin sometimes only to mechanical action. The limestone rock may be worn down by the action of mechanical causes, like any other rock, and the mud composing it may be carried out to sea and deposited like the fine mud composing the schists; but in the great majority of cases the limestone is held in solution in water by the presence of carbonic acid in it, and it owes its exceeding fineness, not to the fineness of the particles into which it has been divided by mechanical forces, but to the fact that it is a chemical precipitate. This chemical deposition of limestone from solution in water may take place, and sometimes does take place, in shallow water as well as in deep. You will therefore recollect, as a general rule, that the three great groups of rocks are distinguishable by the fact of the sandstones being deposited always in shallow water, the limestones sometimes in shallow and sometimes in deep water, and the schists always in deep water.

Before describing the varieties of these rocks that it is necessary to be acquainted with, I shall say a few words as to the general character of their chemical composition. The sandstones, as a class, are composed of quartz; the quartz is almost pure silex. The silex consists of one part of silicon, and three parts of oxygen; it contains a very large pro-

portion of oxygen. The atomic weight of oxygen is 8, which multiplied by 3 gives 24; the atomic weight of silica is 21.4; therefore you observe that in 45 parts by weight of silica there are nearly 24 parts of oxygen, more than half. Quartz is one of the most highly oxidated rocks we are acquainted with; it contains 52.7 parts of oxygen in 100 parts; whereas the granites contain only 48, and the trap rocks 43, and so on, in a decreasing scale. This highly important mineral, silica or quartz, constitutes the greater part of the substance of all the sandstone rocks.

I have already shown, in Lecture I., that the Granitic or Acid Rocks contain only 48 per cent. of oxygen; and as these rocks are mineralogically composed of quartz, felspars, and micas, or hornblendes, we may regard the sandstone rocks as formed mechanically from the granitic rocks, by the degrading action of water, which washes away the silicates, and leaves only the most highly oxidated portion of the granite (quartz) to form the basis of the new sandstone rock.

In order to give you an idea of the average or general composition of the schists or slates, I have taken, for example, this roofing slate of Wales. It is a nearly pure clay. It possesses a definite chemical composition; and yet it is so hardened by a metamorphic cause, which, however, does not appear to have acted on it chemically, and so changed, perhaps by mechanical forces, as to present some of the most remarkable properties of any rock with which we are acquainted. It has the property of cleaving into thin plates, which is not due to bedding or stratification of any kind, but, as geologists now generally believe, to extreme pressure acting

on it when in the state of mud, the line of maximum pressure being at right angles to the plane of cleavage. This slate gives us one of the purest and best of schists for examination; and I lay before you its chemical composition:—

Welsh Roofing Slate. Sp. gravity = 2.824.

	Per-centage.	Oxygen.
Silica,	60.50	32.27
Alumina,	19.70	9.19
Iron (protoxide),	7.83	1.74
Lime,	1.12	0.32
Magnesia,	2.20	0.88
Potash,	3.18	0.54
Soda,	2.20	0.57
Water,	3.30	2.71
	100·03	**48·22**

You will perceive a striking similarity in some respects here to the acid magma of Durocher, which I described in the last Lecture. There is a larger amount of potash and soda in the Welsh slate than is generally supposed. It suggests at once to the chemist and mineralogist who is acquainted with granite the idea of a granite washed into the finest and minutest particles that it is possible to conceive, with the addition of some water, and the abstraction of some silica. This is exactly what would happen if we were to imagine a granite finely divided by the action of water; some of its alkaline silicates would be washed away, and the greater part of the constituents would remain in very nearly the same proportion as before. We may take this analysis as a type of the group of schists.

Here, then, we have a rock which, in its degree of oxidation, and in the important relative propor-

tions of all its constituents except silica, resembles granite. We are forced, therefore, to the conclusion that the great group of schists, or slates, or shales—for these are different names for the same rock—is in reality nothing more or less than granite finely divided, reduced to an impalpable powder, as with a pestle and mortar, and scattered over the bottom of the sea in deep water by the action of marine currents. Wherever, therefore, you have in the deposits of any period of the globe's history large quantities of slates and large quantities of sandstones, you are entitled to draw the conclusion that they were derived principally from the *débris* of the outermost layer of the earth's crust—from the granitic or acid magma; and that as yet the large mass of lime or magnesia which we find to abound in the later rocks had not begun to influence the deposition of strata.

The third group of rocks to which I now direct your attention is that of the limestones. These describe themselves by their very name. Every one knows that limestone is carbonate of lime; under which title may also be included mixed carbonates, such as the dolomites, or carbonates of the two bases, lime and magnesia, which I have shown you are the characteristics of the second layer of the earth's crust. Lime and magnesia are absent, except in such minute quantities as one and two per cent., not only from the granites of the earth's crust, the porphyries, and rocks of that kind, but also from the slates and sandstones which those rocks supplied the materials for making. But when we examine perfectly pure limestone, which is carbonate of lime, consisting of carbonic acid 22 parts, and lime 28 parts, we find, since the sum of these

figures is 50, that we obtain the large amount of 56 as the percentage of lime in limestone. This rock owes its lime to the second, or basic magma of Durocher—the second layer of the globe—and its carbonic acid to the atmosphere. There can be but little doubt that, as a rock, it is subsequent in point of time in the history of the globe to the sandstones and the schists; although, of course, once the materials for making limestone were fairly deposited on the surface of the globe, limestone in the later rocks appears as abundant as either the sandstones or the slates, because we then have these rocks worn down indiscriminately by water, and influenced by chemical action; and, from its very nature, limestone is more easily attacked by these causes than the other rocks, and therefore we find in process of formation in the later periods of the earth's history, as it were, a preponderance of limestone rocks. This has an important bearing on other questions connected with the history of life on the globe, to which I shall hereafter direct attention.

I now come to describe to you briefly the subdivisions of these three great classes of rocks. I divide the sandstones, the schists, and the limestones, with Dr. M'Culloch, in the first place, into simple and compound. The simple and compound schists form the only subdivision that I shall give you of schists; but in the sandstones we are obliged to add a third subdivision, and also in the limestones. This third subdivision is one made for a special purpose, to include a group of rocks that does not occur amongst the slates—the conglomerates and the breccias. No such coarse materials can occur in the slates, because they are formed in deep water; therefore, neither a breccia slate nor a

conglomerate slate could exist. But as limestones are sometimes formed in shallow and sometimes in deep water, breccias or conglomerates may occur in limestone; and they may always occur in sandstone. We therefore divide the sandstones first into the simple and compound, the conglomerates and the breccias; the schists, into the simple and compound; and the limestones into the simple and compound, and the conglomerates and breccias.

CLASSIFICATION OF SANDSTONES.

I. SIMPLE = Quartz only:—
  A. Granular.
  B. Compact.
  C. Splintery.

II. COMPOUND:—
  A. Quartz and felspar (mechanically mixed).
  B. Quartz, felspar, and mica (mechanically arranged).
  C. Quartz and clay (grey or red).

III. CONGLOMERATES AND BRECCIAS:—
  A. Quartz pebbles; and red clay.
  B. Quartz, schist, jasper, gneiss, granite, &c., pebbles; cemented by red clay or siliceous matter.

The simple sandstones are those which are composed of pure quartz; and the compound sandstones are composed of quartz *plus* something else, and they take their name from the material added to the quartz to make them.

Of sandstones formed of pure quartz there are very few. In Ireland we have examples in the coal sandstone, near Cookstown, county Tyrone; and the quartz rocks in the neighbourhood of Dublin. Part of Howth and part of Bray Head are composed of quartz rocks that are pure silica.

Quartz rock differs from these pure sandstones, inasmuch as it is a metamorphic rock as well as a sandstone. It is a sandstone that has undergone

some peculiar change—that has made its particles still finer, and has destroyed the evidence that exists, generally speaking, in sandstones, of their mechanical origin. In most sandstones, including also the conglomerates, the particles of quartz found in them are rounded on the edges, and held together by a cement more or less siliceous; and down to the very finest sandstones, at least of the secondary rocks, such as the coal measure sandstones, the Devonian, and others, you will, by examining them with a magnifying glass, be always able to see the rounded particles sticking in the cement. In the quartz rocks, however, that structure appears to have disappeared, possibly from their being exposed to the infiltration of silica at a considerable temperature, and under the action of water. This silica has so penetrated all the particles of the sandstone rock as to have blended them all into one uniform and compact whole. The pure sandstone rocks are divided into granular—which is the ordinary sandstone, and in which you see rounded particles; compact, and splintery.

The compound sandstones are those that most commonly occur; and when they occur in a coarse form, they are always called conglomerates. A conglomerate is defined to be a sandstone in which there are large particles of quartz, of slate, or limestone, or any rock cemented together by a more or less siliceous cement. The essential idea of a conglomerate is, that all the particles should be rounded, showing that they have been formed by the beating of waves on the sea shore, or by the action of very rapid tidal currents in comparatively shallow water. When the conglomerate is composed of angular fragments, showing that the par-

ticles that make it had not been washed about much by the sea, but remained near the place where they were broken up, it is called a breccia. Limestone breccias, or scagliolas, are very common in Italy, and we have borrowed the term from the Italians; and in this country specimens of siliceous breccia are not uncommon in the older rocks.

The most ordinary impurity with which quartz is found mixed in the sandstones is clay—in fact, mud, more or less resembling the composition of slate, with a good deal of iron in it. Most of our sandstones have a red colour, owing to the peroxide of iron that enters into the composition of the paste. The paste that cements the particles of sand together is generally clay or mud; and a most remarkable circumstance sometimes occurs in the formation of those sandstones which are not composed of pure particles of quartz, but of clay mixed with them—namely, that the particles of quartz mixed in this clay, or paste, are permitted a certain amount of motion. If you take an ordinary sandstone, it is like any other rock; and with a lens you can see the separate particles, and that each separate particle is touched on every side by a number of other rounded particles that hold it in its place, and it in turn contributes to hold them in their places, so as to form of the whole a rigid rock like any other. But, occasionally, in some rare cases—which, as far as I have any knowledge of them, are confined to Brazil, South Carolina, and Delhi—you have a rock composed of particles of sandstone which are not in contact with each other, but lie in a paste of felspathic clay, which paste permits a certain amount of motion between the particles of the mass. So that

the whole rock becomes somewhat like the vertebral column of a bird's neck, with a very small amount of motion permitted in each part; but yet, that small amount of motion being allowed to each, the flexure of the whole may be very considerable. If you take the neck of a swan or giraffe, which contains only a few joints, and attempt to bend it abruptly across, you would find it impossible to do so; yet, if you allow the animal to bend it in his own way, he will swing it through an angle of 180°, and will form the most graceful curves, notwithstanding the small amount of motion that is permitted between each pair of vertebræ. Here is a specimen of sandstone possessing this remarkable property. It is flexible in my hand, yet with the slightest strain it would break. The curve to which it bends measures the amount of motion that is permitted to each particle. Nothing can demonstrate more satisfactorily than this remarkable fact the manner in which the rock is made; it consists of particles of quartz lying in a softer material, which permits a certain amount of motion between each.

CLASSIFICATION OF SCHISTS.

I. Simple = Indurated schistose clay only:—
- A. Straight fissile.
- B. Imperfectly fissile = massive slate.
- C. Whet slate, with splintery fracture.

II. Compound:—
- A. Argil and Mica.
- B. Argil and Talc.
- C. Argil and Chlorite.
- D. Argil and Hornblende.

The schists, or slates, are only divided into simple and compound. When there is much silica in a slate, it acquires the name of whetstone, or whet

slate; which is nothing but a slate with more silica, very finely divided. Slate has every variety of colour, which, of course, will serve for subdivisions; it becomes mixed up, in compound slates and schists, with other minerals. Among these minerals there are four which are so important as to give names to the slates they respectively characterize, viz., mica, talc, chlorite, and hornblende; so that we have mica slate, talc slate, chlorite slate, and hornblende slate. These are doubly divided, as compound schists, consisting of mica and argil, talc and argil, chlorite and argil, and hornblende and argil; and you may imagine "argil," which is an oldfashioned word, to be mud formed by a minute and fine mechanical subdivision of the granitic rocks.

These varieties in rocks cannot be learned from lectures—an eye knowledge of them must be acquired in the field.

CLASSIFICATION OF LIMESTONES.

I. Simple:—
   A. Crystalline.
   B. Compact.
   C. Oolitic and Pisolitic.
   D. Dolomite.

II. Compound:—
   A. Limestone and Mica.
   B. Limestone and Argillaceous schist.
   C. Limestone and Serpentine (verde antique).

III. Conglomerates and Breccias:—
   A. Both pebbles and paste of limestone.
   B. Pebbles mixed (limestone, quartz, slate, &c.); and paste of limestone.

Limestones are divided into simple, compound, conglomerates, and breccias. With regard to the conglomerates and breccias of limestone, there is no difference between them and the conglomerates

and breccias of sandstone. The essential distinction of the limestone breccia is, that some of the pebbles must be limestone, and that the cement mustbe limestone. We call them sandstones or limestones according to the composition of the paste, the physical origin of both being identical. Generally speaking, we do not find many limestone pebbles in the conglomerates in which sandstone pebbles also occur, for this reason: the conglomerates, whether sandstone or limestone, are always formed by the action of waves on the sea shore; and in that action the particles of rock are rounded off, and ultimately the whole shingle beach becomes cemented, either by silex or limestone, into a rock. In such a grinding process, the hard pebbles suffer least, and destroy the softer ones. Hence, on a chalk shore you never find many pebbles of chalk on a shingle beach. You will find here and there a small particle just at the close of its career; but in general there is hardly anything but flints, the flint pebbles having ground away all the chalk into powder. Therefore, sandstone conglomerates are much more common than limestone conglomerates, even when the latter are formed on the sea beach.

The simple limestones are compound in their subdivisions, which resemble the subdivisions of the slates. The simple limestone is either pure limestone, or pure carbonate of lime and magnesia. We subdivide the simple limestones thus, according to their appearances:—There is the crystalline, where you can see the crystals like loaf sugar; the compact, where it has a finer cystalline appearance,

and generally a conchoidal fracture; the oolitic,* so called because its structure is like the roe of a fish, sometimes it is called pisolitic,† when the rounded particles composing the limestone are larger, and resemble a pea. These are only subdivisions of structure to assist in the classification of the limestones. The fourth subdivision consists of pure dolomites; these are generally of a cream colour, but are often blue; it contains nearly equal atoms of carbonate of lime and magnesia. The compound limestones, with which I conclude this lecture, are qualified in the naming of them by the minerals with which they are associated. We call the limestone micaceous, like this from Donegal, when it consists of mica as well as limestone, mechanically added; argillaceous—like this from Kenmare—when it contains sheets of slate mixed with sheets of limestone, making beautiful marble if quarried. Serpentine limestone is a metamorphic limestone, in which the remarkable mineral serpentine has become developed; it is the *verde antique* of the ancients. All these are rocks containing limestone, and may be micaceous, chloritic, talcose, or serpentine limestones.

A most curious and important subject is that of the accidental minerals that are found in these three groups of rocks. I have hitherto spoken only of their constituent minerals; but each of these groups of rocks carries with it its peculiar group of minerals. In the limestones and the slates these minerals are so abundant and so numerous,

* ὠόν an egg, λίθος a stone.
† πίσος a pea, λίθος a stone.

that it would be impossible for you to carry them all in your memory. I have here a list of 24 accidental minerals commonly occurring in limestone, and of 17 accidental minerals commonly occurring in schists; and these minerals are quite different in the one group from those in the other.

But sandstones are remarkably bare of minerals. One cause of this is, probably, the fact that the sandstones are deposited in rough water exposed to the action of considerable force; but another, no doubt, is the barren nature of their chemical composition; they are nearly pure silica, and what mineral can be formed from silica? there are no bases. There are, however, three very remarkable minerals which occur in sandstone, and they are always rare. The garnet is the least rare, the topaz next, and the diamond third. These are found generally in the sandstone rocks; and if we except granite (here regarded as a sort of siliceous sandstone), topaz is confined to sandstones. The diamond is absolutely limited to sandstones, whereas the garnet is common in many other rocks.

CLASSIFICATION OF STRATIFIED ROCKS:—

I.—SANDSTONES.

A. Simple = Quartz only:—
- A. Granular.
- B. Compact.
- C. Splintery.

B. Compound:—
- A. Quartz and felspar (mechanically mixed).
- B. Quartz, felspar, and mica (mechanically arranged).
- C. Quartz and clay (grey or red).

C. Conglomerates and Breccias:—
- A. Quartz pebbles; and red clay.
- B. Quartz, schist; jasper, gneiss, granite, &c., pebbles; cemented by red clay or siliceous matter.

Accidental Minerals in Sandstones.

Garnet, Diamond, Topaz.

II.—SCHISTS.

A. SIMPLE = Indurated schistose clay only :—
  A. Straight fissile.
  B. Imperfectly fissile = massive slate.
  C. Whet slate, with splintery fracture.

B. COMPOUND :—
  A. Argil and Mica.
  B. Argil and Talc.
  C. Argil and Chlorite.
  D. Argil and Hornblende.

Accidental Minerals in Schists.

1. Wavellite.
2. Chiastolite.
3. Staurotide.
4. Andalusite.
5. Brown Spar.
6. Calc Spar.
7. Chlorite.
8. Garnet.
9. Epidote.
10. Stilbite?
11. Tremolite.
12. Kyanite.
13. Topaz.
14. Lazulite.
15. Opal.
16. Pyrites.
17. Magnetic Oxide.

III.—LIMESTONES.

A. SIMPLE :—
  A. Crystalline.
  B. Compact.
  C. Oolitic and Pisolitic.
  D. Dolomite.

B. COMPOUND :—
  A. Limestone and Mica.
  B. Limestone and Argillaceous schist.
  C. Limestone and Serpentine (verd antique).

C. CONGLOMERATES AND BRECCIAS :—
  A. Both pebbles and paste of limestone.
  B. Pebbles mixed (limestone, quartz, slate, &c.), and paste of limestone.

Accidental Minerals in Limestones.

1. Tremolite.	13. Steatite.
2. Sahlite.	14. Garnet.
3. Augite.	15. Emerald.
4. Hornblende.	16. Spinelle.
5. Actinolite.	17. Tabular Spar.
6. Asbestus.	18. Idocrase.
7. Mica.	19. Stilbite.
8. Chlorite.	20. Olivine.
9. Quartz.	21. Pyrites.
10. Brown Spar.	22. Titanite.
11. Schiefer Spar.	23. Sphene.
12. Serpentine.	24. Talc.

LECTURE III.

NODULAR STRUCTURE—FORMATION OF NODULES—CARBONATE NODULES—ROMAN CEMENT—ORGANIC REMAINS IN NODULES—MODES OF FOSSILIZATION—REPLACEMENT OF SUBSTANCE—FOSSIL CASTS.

I HAVE already described the threefold classification of the aqueous or stratified rocks; viz., sandstones, schists, and limestones; and have divided these rocks into the simple and the compound, according as they are found mixed with other materials and other minerals, such as chlorite, talc, mica, and hornblende, qualifying the name of the rock by adding to it the name of the mineral with which it is associated. But in all these cases the mineral with which it is associated is interstratified with it by mechanical action. Whether it be a limestone, a sandstone, or a slate, when it becomes a compound rock we find a layer of slate, a layer of the mineral with which it is mixed, a layer of slate again, and so on. For example, if I speak of a rock as micaceous quartz or limestone, I mean that it is composed for the most part of quartz, or limestone, which is divided into sheets or leaves by the interposition of plates of mica.

There is another kind of structure found in these stratified rocks, called the nodular or concretionary. This structure has a certain resemblance to the impurities I have already called attention to, inasmuch as there is a tendency in the concretions, or no-

dules, to arrange themselves in layers parallel to the plane of stratification. You will find in a bed of rock a row of isolated nodules, or concretions, of this kind. This row at times enlarges, and becomes continuous—is sometimes thin, and sometimes thick, but always lies in the plane of the bedding. This nodular structure, turning into a banded structure, is very well exhibited in the calp limestone of the county of Dublin. You will frequently see a band of black flint in the calp, or impure limestone; and that band will continue in the quarry for many square yards. Then the material of which it is composed appears to die out; and in place of a band of flint you have isolated, flattened nodules, or ellipsoidal concretions of flint, extending in the same plane, however, as the original band of black flint for a considerable distance. This shows the tendency of the nodules of the rock to arrange themselves parallel to the plane of stratification; and in this respect they resemble very much the impurities in the simple rocks described in my last lecture. When the nodules are not sufficient in quantity to form a band, they touch each other; two nodules will run into each other, and you will see a sort of twin nodule formed by their junction. In fact, you will often find a dumb-bell structure, composed of two nodules, with a band of the same material connecting them. The analogy between these impurities in the stratified rocks, however, and the impurities that we have already considered, is more apparent than real, because the nodules owe their origin, not to mechanical forces, but to chemical action.

The principal rules to be recollected with regard to nodules are the following:—first, that they are

arranged parallel to the planes of bedding, and so far indicate a mechanical or physical origin; and, secondly, without exception, that the nodule is composed of a material differing in its chemical composition from the rock that surrounds it. Accordingly, as we have three classes of rocks—sandstones, schists, and limestones—we must have three classes of nodules.

The nodules that are found in sandstones are always carbonates. In a pure sandstone, of course, no nodule occurs. Sometimes you will find in a compound sandstone parallel layers of clay or mud, interstratified with layers of quartz particles; just as you might see mud and sand mixed together, and interstratified by the water in the sea or in a river bed, but the nodule, properly so called, when it segregates itself in the round ellipsoidal form, characteristic of the nodular or concretionary structure, is never composed of either quartz or clay; it is always composed of carbonates of lime, of magnesia, or of iron. This is a property well known to farmers in many sandstone districts. In Herefordshire, for example, these bands of nodules in the red sandstones are called corn stones, because they are dug out by the farmers, burned for lime, and used to manure the land. It has often surprised persons passing through Herefordshire why it should be such a fertile county, seeing the barren red sandstone of which it is composed. The reason is, that the sandstone is not pure, but contains numerous beds or bands of nodular corn stones, which, by the disintegration of the weather, and still more by the art and skill of the agriculturist, are brought to aid the otherwise poor soil formed from the sand and clay of the red sandstone.

In the second class of rocks, the schists, we have a different kind of nodule, and, indeed, we find a greater variety in the clay or schistose rocks than in any others. The nodules are carbonates of iron, carbonates of lime, and mixtures of these two. These may be regarded as one group of nodules; secondly, we have rock salt; and, thirdly, gypsum. The carbonates of lime and iron may, as I have shown, be found in sandstones; but they are most commonly found in clay. And here it must be remembered, that geologists use the term rock in a sense which is not popular; we call a bank of clay or a bed of sand a rock, for each of them occupies a definite geological position. Commencing with beds of clay, we find evidences of a nodular structure forming in soft beds of clay which in popular language would not be called rocks. Here is a concretion of carbonate of lime found in a clay bed near Tallaght; but the interest of the specimen consists in the insertion of a chip of wood round which the concretion has evidently formed. It is a common circumstance in nodules, that in their centre you find some foreign substance which served as the original point of attraction round which the mass crystallized and formed, and afterwards grew. Many persons suppose this foreign substance to be necessary for the formation of the nodule; but this is not, accurately speaking, the case; it however points at once to its chemical origin. It shows that the water from which these deposits were being formed is to be regarded as somewhat in the condition of a salt in solution, ready to crystallize—containing in solution the material, the carbonate of lime which makes the nodule. Just as, in some saline solu-

tions, the dropping in of a little pebble, a feather, a particle of dust, or, above all, a crystal of the salt itself, will instantly compel the whole of the salt in solution to crystallize round the foreign body, so we believe that these nodules were frequently originated by the foreign body, which often forms a centre round which they collect.

Many valuable nodules of iron in South Wales, and other districts, owe their origin to this cause. One which miners know by the name of clay ironstone, is a carbonate of iron mixed with carbonate of lime, and often carbonate of magnesia. It is found in these ellipsoidal masses, which you will always recognise by their weight, in the shale beds which invariably overlie the coal. In the coal measures we have a great number of sandstones, and a great number of shales alternating, and very little limestone. You never find the nodules in the sandstone of the coal measure; but there is scarcely a coal measure whose coal shales do not contain nodules of carbonate of lime and iron. These form the principal sources of the iron ore of the famous collieries of South Wales.

The ferruginous carbonate which we, with national pertinacity, still call Roman cement, though it comes from London, owes its origin to the same cause. The Roman cement of traders does not now come from Rome at all. The original cement came from Rome, and is a volcanic ash, a rock as different in its chemical composition as can be imagined from that which is now universally used in this country as Roman cement. It is a ferruginous volcanic ash, which serves as a hydraulic mortar. In the London clay, which is composed of beds of soft tertiary clay, nodules occur of carbonate of lime and iron, formed

just as in the cliffs of the county of Clare, or of Dorset, or the ironstone patches of South Wales. They are ferrocalciferous carbonates, with one important impurity which gives them their whole value. In the act of segregating themselves from the surrounding mass, they entangle a certain quantity of the very finest particles of silica, absorbed from the surrounding mud. To this, I believe, they owe their property as hydraulic mortars. This so-called Roman cement consists of carbonate nodules found in shale or clay beds, and comes from London, and from the coast of Harwich, where it is dredged up like oysters. The sea dashing against the clay cliffs washes them away, and leaves large nodules of the cement lying at the bottom of the sea. These the boats dredge for and bring up. I remember being once told by a Harwich fisherman, who had given up oyster fishing and taken to dredging for Roman cement, and had made much money by the change of occupation, that he was anxious to go out to Australia as a gold-digger; and he explained to me his views. He was to raise a company (limited, I presume), hire a large dredging schooner, and lie off the coast where the diggings were, and dredge the bottom of the sea; because, he said, that as the gold diggings no doubt extended out to sea, as the clay did at Harwich, it would be much easier and better to dredge for the gold, at his ease in the schooner, than at the risk of his life and health to search for it on land.

The Roman cement of Somersetshire and Dorsetshire is found in a totally different class of rock —in the shale beds of the lias period. It is also got at Kimmeridge, in the oolitic beds of the Kim-

meridge clay. You will therefore observe that this carbonate nodule may occur in a pure clay rock—in the pure clay of the gravel about Dublin, which is post-tertiary; in the pure clay of London, which is tertiary; in the Kimmeridge clay, which is oolitic; and in the lias clay. It might also occur in clay deposits of any age of the world.

I now come to rock salt and gypsum, which are nodular, or rather banded in their structure. Lenticular would be a better term to apply to these masses than nodular. A nodule evidently indicates only a small quantity of the material from which it is made; but a lenticular mass runs for a greater length, always parallel to the stratification of the beds, and thins out at each end. Rock salt and gypsum are generally associated together. You may find gypsum without rock salt; but I believe you cannot find rock salt without gypsum. This gives us a key to the origin of these lenticular masses. They must have been formed from sea water, from the gradual evaporation of the brine of sea water; for, next to chloride of sodium, sulphate of lime is the most common and abundant result of the evaporation of sea water; and we can easily understand why, when rock salt and gypsum occur together, the gypsum may be found while the rock salt is occasionally absent. If water percolate through the rock, it may be sufficient to wash away the rock salt, but not the gypsum. A sufficiency of water would wash away sulphate of lime as well as chloride of sodium; but in general it is not possible that water can have had access to a bed of rock salt since it was formed.

I now come to the third class of nodules, namely, those that are to be found in limestone. These

are only flint, the siliceous nodule being peculiar to limestone. Just as the limestone nodule is peculiar to flint and sandstone rocks, so the flint nodule is peculiar to the limestone rocks. This flint goes by every variety of name; when we find it in chalk, it is commonly called gun flint, or chalk flint. And in the chalk flints you find the same law of nodular structure that I have called attention to in the specimen from Tallaght, in the county of Dublin. You will very often find a foreign substance in the interior of the flint. Frequently the flint is hollow, only occupying the outer coat of the mass; and the interior is filled by a sort of decomposed substance, which is generally the remains of a sponge. It is a very interesting fact that a sponge is commonly found in the interior of chalk flints, because it shows how completely the formation of these flints was the result of chemical action. I shall explain in a future lecture that the skeleton, if I may call it such, of the sponges is always composed of silica. Therefore, when the sponge is floating about in the sea, putrifying, the organic particles are deposited, and the skeleton containing the siliceous spiculæ of the sponge, as the part that resists longest the action of the sea, ultimately sinks to the bottom, and becomes blended with the limestone already forming. But if silica be in solution in the sea water where these sponges are decomposing, then we have the condition I have already alluded to of a salt tending to crystallize out; as if crystals of the same salt had been put into the liquid, the silica in the solution collects round the spiculæ of silica in the sponge, and gradually lays the foundation for the formation of these nodules.

There are other nodules which are not so common, but which sometimes become important from their chemical value as ores. I hold in my hand a very remarkable specimen of this kind of nodule. It is from the interior of Africa, and has been cut in two. It was found in a sandstone. The interior of it was filled with soft white sand; and the nodule itself, which was of a spherical form, is composed entirely of peroxide of iron. It was supposed by the natives to be a thunderbolt, and was, I believe, an object of religious worship amongst the tribe from whom it was taken.

Here is another remarkable example of nodular structure, which sometimes occurs in sandstone. It owes its origin to oxides of manganese and of iron filtering through the sand, and stopping at a certain point. When they could percolate no farther, they collected round some centre according to the nodular law of arrangement. Generally speaking, the nodules of oxide of manganese and iron that we find in sandstone are pipes terminating in cavities more or less large. This, I suppose, was the end of one of these pipe-like nodules.

The reason I have dwelt at such length on the question of nodules is from its connexion with the theory of fossilization, upon which it throws great light. A fossil is either an organic substance, or certain evidence of an organic substance, which we find embedded in the rock. From this statement of what a fossil is, it is evident that all the soft parts of animals and vegetables must be excluded. All these putrefy, or decompose, resolving themselves into gases, and disappear. They never could be preserved in a fossil condition. We are therefore obliged, in considering fossils, to restrict our-

selves for the most part to the hard parts of animals and vegetables. In some cases, however, we consider as a fossil certain evidences of the existence of an animal, although they are not part of the animal itself.

I divide fossils into four classes:—

First, the actual substance; secondly, the substance replaced by other substances; thirdly, the cast or mould of the substance—and this may be either of the hard or the soft substance; and, fourthly, those fossils which are now generally called physiological impressions, such as footprints, being certain evidence of the animal having been there. These, if you like, might be reduced to the third class of casts. They are casts of the soft part of the animal as he walked over the bed of mud or sand.

The actual substance itself, as a fossil, is much rarer than is generally thought. It is restricted, as far as I know, to the shells of mollusks observed in pure limestone; to the bones, teeth, and coprolites of animals observed in any kind of rocks; and to the remains of those minute animals that have siliceous skeletons. The shell of the mollusk contains on an average 95½ per cent. of carbonate of lime, the rest being made up of minute traces of phosphate of lime, organic matter, and water. It is necessary for the preservation of such a substance as this, according to chemical laws, that it should be deposited in nearly pure carbonate of lime, because it is itself of the same nature; and when it is deposited in such a material, no chemical action can take place between the two substances, and they lie together in contact without destroying each other. The bones, teeth, and coprolites, or

dung of animals, and particularly of fishes, are totally different in their constitution. The bone of a mammal contains 54 per cent. of phosphate of lime; and the great bulk of the remainder is composed of organic matter, which is not capable of being made fossil at all. The coprolite of the carnivorous animals contains 62 per cent. of phosphate of lime, the bulk of the remainder being organic matter and water; and in the coprolite of birds we have 35 per cent. of phosphate of lime. Therefore, in all these classes of fossils the carbonate of lime becomes of small importance compared with the phosphate. It is cut down to 11, to 15, and to 34 per cent. respectively. It is therefore evident that the preservation of the bones, teeth, and coprolites of these animals becomes a question of the chemical conditions under which the phosphate of lime will be able to preserve itself. Phosphate of lime can be preserved in any kind of rock, neither silica, clay, nor carbonate of lime having any effect upon it. We are not acquainted with anything which can seriously injure a deposit of phosphate of lime, except large quantities of carbonic acid, or other organic acids, in solution; and these do not get free access to the fossil phosphates; therefore they preserve their original condition. But while we see that the bones, teeth, and coprolites of animals are preserved, so far as their phosphate of lime is concerned, you must remember that a very important change does take place in them. Let us take as an example the bone of a mammal. It contains 34½ per cent. of organic matter and water. This organic matter and water disappear in the process of putrefaction by the action of water, to which it is exposed in the rock. The cavities or

spaces which are left in the interior of the bone by the action of this putrefaction, and the percolation of water, may and generally do become filled up with mineral matter. Very commonly, when the bone is deposited in limestone, these interstices become filled with crystallized carbonate of lime; so that the fossil bone, when analyzed, will contain, we will suppose, 54 per cent. of phosphate of lime, and the remainder will be pure carbonate of lime, or sometimes peroxide of iron, with, it may be, a large quantity of silica mixed with it. This increases the specific gravity of the mass; so that the fossil bone has always a higher specific gravity than the recent bone. This is the process that we call fossilization; but all these cases that I have spoken of hitherto belong to the first group of fossils, in which the original substance is preserved.

The third kind of fossil in which we have the actual substance preserved, is the case of those that have siliceous skeletons. These are the small diatomaceæ and other fossils of that kind, very low in the scale of organization. They have begun to be recognised lately as forming an important part in some rocks. They are pure silica; and it is difficult to conceive how they can be destroyed by any fossilizing cause.

The most remarkable case of a substance become fossil, and replaced by another substance, is that in which the shell of a mollusk, consisting of carbonate of lime, becomes converted into flint. This is one of the most wonderful circumstances we are acquainted with in the act of fossilization. I hold in my hand a shell which those of you who are not very familiar with shells would confound probably with some of the common shells of the sea shore.

Instead, however, of being composed of carbonate of lime, it is composed altogether of flint; and this replacement of the carbonate of lime by flint is not like the filling up which I have already described to you, of the interstices of bone formerly occupied by water and organic matter with foreign mineral substances; but it is an actual destruction of the original carbonate of lime that formed the shell, and a replacement of it, molecule by molecule, by the chemical action of another substance of a totally different character, named silica. This replacement is so perfect, and is conducted on such a minute scale, that a polished section of the shell examined under a microscope would show the same structure that the original shell composed of carbonate of lime would show.

The third group of fossils contains those which we call casts and moulds; and these are exceedingly common. When a shell is deposited, not in pure limestone, it must be destroyed. It consists of carbonate of lime; and it is deposited either in impure limestone, or in clay, or in sandstone. In the sandstone and clay there is silica ready to attack it, and to destroy the shell. In some rare cases, as in the last class of fossils, silica destroys the shell, but takes its place, acquiring its form; but in the great majority of cases nothing whatever is left of the shell. It is all washed away, principally by the action of the silica in forming soluble silicate of lime; but before this slow process of washing away the shell has been completed, the rock round the shell has consolidated and hardened, so that a cavity is left corresponding with the shell. This cavity retains the form and impression of the original shell, and it is, in fact, a

natural cast. In those fossils, therefore, which are casts, you do not find the shell; but you find a natural cast of either its interior or exterior. If you secure the portion of rock that surrounds the shell, you will sometimes get a cast of the outside and of the inside in the same specimen, with a space between them, the thickness of which corresponds to the thickness of the original shell. On these grounds some geologists have proposed that instead of spending so much time in the study of the shells themselves, with a view to improving ourselves in the knowledge of fossils, we should rather study their casts; and by filling bivalve and other shells with plaster of Paris, taking artificial casts of them, and comparing those with the natural casts found in the rock, a great deal of important light has been thrown on the study of fossil shells. You will find a hundred fossils of this kind for one of either of the first two that I have called your attention to. They are, therefore, incomparably the most important of all the group of fossils. It must be a chance of more than a hundred to one that when the animal inhabiting a shell dies, and the shell falls to the bottom of the sea, it should come upon a kind of mud, the chemical composition of which is so close to its own chemical composition as to prevent any destructive action between the two. In the majority of cases it must fall into mud of a different composition, and must therefore undergo a serious disintegration.

The last group of fossils are those that we call physiological impressions, which might indeed be reduced to the last class, if we included casts of the soft part of an animal in our definition of casts.

An animal may walk over a bed of clay or sand, and leave the impression of his foot. A mollusk may travel along the sand, and leave the print of the muscular disc on which he walks; or, as recently has been shown, a small crab may burrow in the sand or mud, and leave a track behind him, having all the appearance of a worm-track; or the worms themselves may burrow, and leave the mark of their former presence in the rock. When this rock consolidates, the burrow of the worm, the sand which he has swallowed and passed through his body, or some other evidence of the presence of the worm, the crustacean, the mollusk, the large reptile, or of the bird will be found, as the next return of the mud and of the tide along the sea shore will have taken a natural cast of the mark which was left. These are all called physiological impressions; but they might be included, as I said before, in the last group of fossils.

CHEMICAL COMPOSITION OF FOSSILS.

Shell of Mollusca.		Bone (Mammalia).	Coprolites. Mammals.		Coprolites. Birds.
Carbonate of Lime, . . .	95.50	11.30	Carbonate of Lime, . . .	15.00	34.77
Phosphate of Lime, . . .	1.50	54.04	Phosphate of Lime, . . .	62.50	39.60
Organic Matter, ...	1.75	34.66	Organic Matter, ...	5.00	12.56
Water, ...	1.25		Water, ...	12.00	
			Argil, ...	5.50	13.07
	100,00	100.00		100.00	100.00

In the teeth of Mammals the Phosphate of Lime ranges from 60 to 66 per cent. of the whole.

Fossilizing Substances.

1. Silica.
2. Carbonate of Lime.
3. Iron pyrites.
4. Sulphate of Barytes.
5. Gypsum.
6. Brown Hematite.
7. Vivianite (Phosphate of Iron).
8. Carbonate of Iron.
9. Copper Pyrites.
10. Sulphuret of Copper.
11. Galena.
12. Cinnabar.
13. Calamine and Blende.

LECTURE IV.

GEOLOGICAL TIME—THEORY OF SOLAR HEAT—THE GEOLOGICAL CALCULUS—TESTS OF AGE—MINERAL COMPOSITION—CHARACTERISTIC FOSSILS—TOTAL THICKNESS OF STRATA—CHANGE OF SPECIES—PROGRESSION OF LIFE.

HAVING considered the chemical composition and mechanical deposition of the stratified rocks, and the principal conditions under which the hard remains of the animals and plants which once lived on the surface of the globe came to be deposited in those rocks, I have now to call attention to the highly important question of the relative and absolute age of those rocks. Any person who has paid even the slightest attention to the science of geology must be aware of the fact, that the whole of our knowledge with regard to age in this science is confined to relative age, and that with respect to absolute age we have little or no real information; and in this absence of positive knowledge as to the absolute age of rocks, geologists have sometimes indulged in the wildest and most extraordinary statements and speculations. They speak of the enormous lapse of time requisite for the formation of exceedingly small quantities of rock in a manner that would almost make us suppose that some miraculous agency was at work to retard the progress of the formation of these rocks. Indeed, it has been well observed that the mantle of the preachers has fallen on the geologists, and that the

figures and images by which the former paint to their terrified audience the duration of eternity *a parte post*, have been seized on and adopted by the geologists in endeavouring to describe eternity *a parte ante*. The infinite time of the geologists is in the past; and most of their speculations regarding this subject seem to imply the absolute infinity of this time—as if the human imagination was unable to grasp the period of time requisite for the formation of a few inches of sand or feet of mud, and its subsequent consolidation into rock.

Professor W. Thomson* of Glasgow has recently published a speculation, which, if well founded, is calculated somewhat to shake our faith in the great length of time that geologists suppose to be requisite for the formation of the rocks of different periods of the earth's history. He has calculated the amount of heat emitted by the sun per square foot, and finds that he gives out at present an amount something between fifteen and forty-five times that which is produced by a locomotive furnace per square foot of grate bars. Now, this is a quantity of heat that is not at all beyond our conception, and that we are quite capable of understanding, and a careful consideration of the subject of the heat of the sun will show the necessity there is for something extraneous to the sun itself to keep up this extraordinary combustion.

Although in the days of Sir Isaac Newton chemistry was almost unknown, except in the form of alchymy, yet it is well known that this distinguished philosopher felt the difficulty of the sun always giv-

* Phil. Mag., 4 Ser., xxiii. 158.

ing out heat and light, which he considered to be material, without some source of renovation. He has accordingly expressed the opinion,* that perhaps comets are the food or fuel that supply the sun with heat. We appear to be returning in modern times to a speculation very like that of Newton. It is considered by many persons, astronomers and others, that the meteoric stones and other bodies with which the whole of interplanetary space appears to be more or less filled, restore, in some form or other, a portion, at least, of the heat which the sun gives out. It is well known that modern philosophers, including Mayer, Joule, and others, have established the possibility of turning heat into motion, and motion into heat. You are familiar with this fact in a thousand instances. You can convert heat into motion by taking a few tons of coal or coke, putting them into a locomotive furnace, and travelling along the rails by the aid of their combustion, and if you attempt to stop a body in motion, we all know that the friction may be sufficient to cause very great heat. These two converse actions of the transformation of motion into heat, and of heat into motion, have been proved to be perfectly equivalent to each other. And therefore the speculation which assigns as one cause, at least, of the heat of the sun, the falling into his surface of enormous quantities of the meteoric bodies now circulating round him is a probable one. As each of these bodies falls into the sun, a certain amount of motion must be destroyed; the motion stopped must produce its equivalent of heat; and so, without taking account of chemical

* *Vide* Appendix (A).

combinations that may take place, a quantity of heat would be generated by these bodies. Those who speculate on this subject have even gone the length of calculating the weight of meteoric matter that must fall into the sun annually, in order to supply the heat which is emitted by the sun, and when this calculation is made, we find that the number of meteoric stones that probably fall into the sun falls very short of the quantity required. We are therefore driven to the conclusion that the sun is gradually cooling, and that the time will come when, if the earth continue at the same distance from the sun at which she is at present, organic life will cease to be possible upon her surface. There may, however, be some compensation for this cooling of the sun in the fact, that the earth gradually approaches the sun each year. No matter what the weight or magnitude of the planets may be, it has been demonstrated by astronomers that they are gradually approaching the centre of gravity of the whole system; and that our fate is, like that of the meteorites, ultimately to approach the sun and become absorbed in its mass. It is therefore quite possible that, by a balance of causes, the diminishing heat of the sun may be compensated for by our nearer approach to him.

Professor Thomson has made an attempt to calculate the length of time during which the sun can have gone on burning at the present rate; and has come to the following conclusion:—

"It seems therefore, on the whole, most probable that the sun has not illuminated the earth for 100,000,000 years, and almost certain that he has not done so for 500,000,000 years. As for the

future, we may say with equal certainty that inhabitants of the earth cannot continue to enjoy the light and heat essential to their life for many million years longer, unless new sources, now unknown to us, are prepared in the great storehouse of creation."*

This result of Professor Thomson's, although very liberal in the allowance of time, has offended geologists, because, having been accustomed to deal with time as an infinite quantity at their disposal, they feel, naturally, embarrassment and alarm at any attempt of the science of physics to place a limit upon their speculations. It is quite possible that even a hundred millions of years may be greatly in excess of the actual time during which the sun's heat has remained constant.

Respecting, therefore, the question of absolute time in geology, you must understand that we are perfectly and totally ignorant about it, except so far as such speculations can throw light upon it. Indeed, one of the most enlightened of our geologists, Professor Phillips, of Oxford, recently, in the Geological Society of London, expressed his own doubts respecting what he calls the "geological calculus,"† and the enormous drafts upon time which geologists frequently feel themselves compelled to make.

We therefore confine our whole attention to the question of relative time; and here, no doubt, geology has a most certain and positive basis to rest upon.

We have three tests, and three only, of relative age. The first is the physical test of age; the second

* *Vide* Appendix (B). † *Vide* Appendix (C).

is the test of mineral composition; and the third is the test of characteristic fossils.

I shall say a few words on each of these tests. The physical test of age applies both to the stratified and to the unstratified rocks. When we find an unstratified rock piercing another rock, whether stratified or not, in a dyke or vein, we believe that the unstratified rock was liquid when it penetrated the rock that surrounds it, and that in that liquid condition it penetrated the mass of a pre-existing rock. In such a case as this, no one has any hesitation in saying that the rock that penetrates the other is newer than it in point of time. When, again, a stratified rock includes fragments of another which can be identified, as in the case of conglomerates or sandstones, no one can have any hesitation in saying that the included fragments or pebbles that go to make up the rock are older than the rock into whose composition they enter. And, thirdly and lastly, in the stratified rocks, when we find a series of rocks lying on each other nearly horizontally, we can have very little hesitation in asserting, if we believe that these rocks were deposited as mud or sediment from water, that the uppermost is the newest, and the lowermost is the oldest. These exhaust what we may call the physical tests of age in rocks.

The second test of age, namely, the mineral composition of rocks, is one respecting which very great diversity of opinion continues to exist among geologists. With regard to the igneous rocks, the French and German geologists are disposed to believe, that the older igneous rocks may be distinguished from the newer by definite chemical composition and the minerals which they contain.

I give you an example or two of this. The German geologists would say, that the igneous rock that contains hornblende must be older than the rock that contains augite. Now, hornblende and augite, although not the same mineral, are closely related to each other; and it appears strange that minerals so closely related should continue to have a different position with regard to age. I believe there are many facts that tend to confirm the truth of this opinion, although it appears, at first sight, so strange a one. Again, they would say, that lime felspars—labradorite and anorthite—always belong to newer rocks than the alkaline felspars—orthoclase, oligoclase, and albite. These views quite agree with what I explained to you of Durocher's theory of the two layers of the globe, the outer layer and the inner, each characterized by a definite chemical composition. We should expect, when we have a granitic magma in the outer layer of the globe, and a trappean magma in the second layer, that eruptions of the former would take place earlier than those of the latter, through the fissures originally formed in the solidified surface of the globe.

English geologists, as a class, reject the whole of this theory of the age of igneous rocks being determinable by their chemical composition. The belief in mineral composition as a test of age is as old as the celebrated Werner, and has always held its ground in Germany, and is now beginning to revive in this country. But, at the same time, we must remember that the arguments of the English geologists on this question are not to be set aside lightly. They say, and with truth, that when an igneous rock penetrates an older

rock than itself, not only does it metamorphose the rock it penetrates, by the action of heat and by its having a different chemical composition, but also the surrounding rock reacts in the most striking manner upon the composition of the rock that invades it, and alters the character of that rock. I had myself an opportunity of observing, I believe, one of the most remarkable cases in which this occurs, in the county of Louth. The granite of that county near Carlingford penetrates, at a place called Grange Irish, the carboniferous limestone, and, as a result, converts it into the finest crystalline marble; but it is itself converted into syenite, the intruded rock ceasing to be granite, and becoming a lime syenite. The lime of the limestone fluxed the granite, removed its alkalies, took their place, and so converted it into a syenite composed of hornblende and anorthite. On part of the mountain where this change occurs, at the back of Grange Irish, the following remarkable deposit may be observed:—The mountain composed of syenite is found to have, here and there, sticking out on its side, patches of crystalline limestone, in nearly horizontal layers, at the height of upwards of a thousand feet above the sea. One patch, in particular, near the top of the hill, is not larger than 20 yards by 10 yards, and is about 12 feet thick; it is itself altered, and has altered the granite into syenite. This shows that the limestone was in excess, and that having done its work in fluxing the granite, and converting it into syenite, the surplus of lime was left standing on the mountain in this condition. English geologists, as a class, believe that the composition of igneous rocks is more dependent on such causes as those which are

called metamorphic—or, as it has been proposed to say, endomorphic—than upon others. It has been proposed to call the action of the granite upon the penetrated rock, metamorphic, and the reaction of the stratified rock upon the granite endomorphic; but I do not think the latter a good term; metamorphic is clearly applicable to both. This metamorphosis certainly complicates the question of the age of igneous rocks as determined by their chemical composition; and we cannot accept, as an absolute fact, the assertion that definite chemical composition in igneous rocks corresponds with definite geological age. But we may, I think, admit it as a general basis on which to start in our theory, remembering that it is continually and constantly modified by such effects of metamorphism as I have called attention to, and on which English geologists have fairly laid very great stress.

With regard to the stratified rocks, their mineral composition is to be taken very cautiously as an indication of age. We are accustomed to speak of the chalk formation, of the old red sandstone formation: I take these two as examples, the one of limestone, and the other of sandstone rocks. Throughout the greater part of Europe, it is quite true that rocks of the age of the chalk are all chalk, or something like chalk; although, even in Europe, we have exceptions to this in the chalk of Saxony, which is sometimes sandstone, and sometimes chalk. But when we cross the Atlantic, and go to America, we find that the rocks of Texas, Mexico, and the Western States, which correspond in age to the chalk of Europe, are almost all composed of sandstones, which would not be recognised by an English

geologist as having any relation whatever to the chalk of his own country. Therefore it is only within certain restricted districts, that the chemical composition of a rock can be regarded as of importance as testifying to its age. In any part of Europe, you may fairly say, when you see chalk, that you know the age of the rocks in which you are. You will not find chalk amongst the Silurian or the oolitic rocks of Europe; nor will you find sandstones amongst the chalk, except in that part of Saxony to which I have referred. Let us take, again, the old red sandstone belonging to an older period of the earth's history. Throughout a large part of Europe, the old red sandstone, as has been said, is old red sandstone; but, as some English geologists expressed themselves on visiting the west of Ireland, it has there sometimes turned grey, probably from old age. The old red sandstone rocks of Dingle are all grey rocks; some of them are slates; and, when we pass to Germany, they have become limestones. For this reason, old red sandstone rocks are now called Devonian, in order that we may not call by the lithological name of sandstone, rocks that may be sometimes limestone, and sometimes grey slates. But it should be remembered, that the sameness of chemical composition often extends over very large districts, and in some more than in others; and, as a rule, the older the rock is in the history of the world, the greater will be the area over which its chemical composition and character remain unaltered. Thus we find, in the oldest Silurian rocks, and in the carboniferous limestone, a sameness of lithological character that is very surprising, over very large tracts of country. In the Silurian rocks of

North America, the muddy limestones and fossil shells that abound and occupy the surface of a large part of that continent are absolutely undistinguishable in character and appearance from the corresponding muddy limestones of Shropshire, and of Bohemia; and the carboniferous limestones of England and Ireland are found again in the United States, in South America, in the Ural mountains, in China, and in Australia. You could hardly tell a piece of carboniferous limestone from the county of Kildare from a corresponding piece of carboniferous limestone from near Pekin. Accordingly, this sameness of chemical composition is a very important quality for the geologist to bear in mind, and it is a quality in rocks respecting which he must educate his eye. It is impossible to describe it, for we cannot write a description of carboniferous limestone, or of chalk, or of roofing slate, in such a way as that another person shall infallibly recognise it, and the practical geologist must, in this respect, cultivate the *oculus eruditus*.

Our third and last test of age in rocks is, the test of characteristic fossils. In characteristic fossils we have a most powerful aid to the study of geology. At one time it was thought that every group of rocks that was formed in the history of the world had a peculiar and remarkable group of fossils, which invariably characterized it. This was the opinion of William Smith, who first taught us the value of these fossils. He found that he could recognise, in England, every bed, no matter how thin, of the oolitic deposits of the centre of England, by means of their characteristic shells. It was generalized from these facts, that every group of rocks had its peculiar and characteristic

fossils, and that it would have these wherever it was found. This generalization, like most others made in the commencement of science, was too hasty; and we now know that, in similar groups, although many of the fossils are identical over very large tracts of country, yet, when we come to compare the fossils of one part of the world with those of another, we are frequently unable to say that they are absolutely identical, but only that they are very like. The group of fossils that is supposed to characterize the Silurian period is found in America, in England, and in Sweden; but, on a minute examination of the representatives of the group from each of these three places, although at first sight you would pronounce them to be the same, yet palæontologists are able to determine slight differences characterizing each. Therefore the phrase has come to be used, that the "facies" of the fossil fauna or flora of a given period is the same; although, in the individual fossils which compose that fauna or flora, and give the lineaments of the facies, or face, as imagined by naturalists, differences may be perceived in different places. Still, for practical purposes, if you are acquainted with the carboniferous fossils of Ireland, even roughly, it would be impossible for you not to recognise the Carboniferous formation in any part of the world in which you may happen to meet it. If you are acquainted with the trilobites of Wales, or the graptolites of Waterford, which are characteristic Silurian fossils, you would inevitably recognise the corresponding fossils from any part of the world, although not identical in species; and this is a kind of knowledge which is an accomplishment essential for the geologist who travels.

I have now to call attention to the conclusion that geologists have derived from the application of these tests of age. They are summed up in the following Table, which is arranged according to the thickness of the strata composing the different groups of rocks :—

TOTAL THICKNESS OF STRATA.

		Feet.	Geog. Miles.
Eozoic.		26000	4·333
Lower Palæozoic .	Lower Silurian	25000	5·082
	Upper Silurian	5500	
Upper Palæozoic .	Devonian. . .	9150	4·458
	Carboniferous.	14600	
	Permian . . .	3000	
Neozoic	Triassic . . .	2200	4·512
	Jurassic . . .	4590	
	Cretaceous . .	11283	
	Nummulitic .	3000	
	Tertiary . . .	6000	
			18.385

		Feet.
Eozoic. . . .	Quartz Rock.	26000
	Roofing Slate	
	Primary Limestone	

You observe that the whole series of rocks, commencing with the lowest, and ending with the uppermost, may be divided into four nearly equal groups—the eozoic, the lower and upper palæozoic, and the neozoic ; the neozoic meaning those characterized by the newer forms of life ; the two palæozoic, those characterized by the older forms of life ; and the eozoic, those in which the first traces of life have been formed. If you divide the total

thickness of the strata, which is 18⅓ geographical miles, into these four groups, you will observe that they are of nearly equal thickness. The eozoic group is 4⅓ geographical miles thick; the lower palæozoic, 5 miles; the upper palæozoic, 4½ miles; and the neozoic, 4½ miles also. There are excellent grounds for believing that, although we cannot tell the absolute age of a rock, or the length of time requisite to form a given thickness, of any kind, yet that the thickness of rocks is the truest and best measure we have of the lapse of time. It is, therefore, exceedingly probable that these four great periods of the earth's history are of nearly equal value in point of duration; but, with regard to geological interest, they are of very different values. The eozoic rocks, during whose deposition but little or no life existed on the globe, have an interest for the mineralogist, for the chemist, and for the student of physics and of forces applied to the deposition of those rocks. The lower and upper palæozoic rocks, which are called by the same name palæozoic, indicating a similarity in their organic contents, are of twice as great importance as regards lapse of time as the neozoic rocks, which are only half their thickness. Yet geologists have always considered that the neozoic rocks contained a much larger amount of organic life than the palæozoic, although it is highly probable that the palæozoic rocks took twice the time to form. If you adopt, then, the thickness of rocks as a chronometric scale—and it appears to be the best measure of time that we have—you will arrive at once at the important conclusion that, as the world grew older, not only did the time arrive

when organic life commenced to appear upon the globe, where before there was no life whatever, but also, that during equal successive intervals of time a greater amount of organic life existed on the globe, and in greater variety. We shall find, for example, as many species of fossils in a mile and a half in the later period of the tertiary rocks as we should find in the whole of the lower palæozoic, which is upwards of three times its thickness.

In this respect geology resembles history. The historian does not count the importance of the history of a nation merely by the lapse of time—by the number of centuries that the nation has existed. It is possible for an intelligent and bold people to compress into a hundred years, events of more value and interest than a slower moving nation could effect in a thousand. As one of our poets sings :—

"Better fifty years of Europe than a cycle of Cathay."

The thousands of years of China and of Eastern despotisms do not contain as many facts as a hundred years of Greece. Some such comparison appears to be just, with regard to the history of the world. In the older periods there were, in all probability, as many animals on the globe at any given time as there are at the present moment; but there were more of the same kind; there was less variety, and they were more uniformly scattered over the globe; and therefore you will find that the characteristic fossils of the older rocks are more universally distributed than those of the modern rocks; and that the doctrine of characteristic fossils, which it is so difficult to apply, and which appears so erroneous when we come to the later rocks, was absolutely

and rigorously true of the older rocks. In the Silurian and Carboniferous, and even later, in the Jurassic rocks, you will find the same fossils over larger tracts of country than you do in the chalk and tertiary rocks which follow them.

There was not, therefore, in the palæozoic period, a less amount of organic life on the globe, but there was less variety in it; and to this we must add the very important fact, that not only was there a less variety and a smaller number of species, though perhaps an equal number of individuals, but that the organic life itself was of a lower, a more imperfect, and a less highly organized type. If we confine ourselves to the broad distinctions that exist amongst the various races of animals, and indeed we may say of plants, there is no fact more certain in the history of the globe than that as the world grew older, a greater variety of species were introduced upon its surface; and those species and creatures that were so introduced became higher and higher in their organization, until the Creator was pleased to crown the whole series by the introduction of man himself. This is the view put forward originally by Cuvier; and I believe it is stated by him in a manner which is still quite unobjectionable, if we except the catastrophes and convulsions which Cuvier thought it necessary to introduce in the history of the earth, for the purpose of destroying one set of creatures on its surface before the next were created. Geologists do not now generally believe in these violent, sudden, and universal catastrophes. We are disposed to believe that according as the condition of the world changed, by loss of heat, by the fixing of its carbonic acid, by the altered constitution of its

atmosphere, and by other causes that we are not acquainted with, it became gradually fitter for the more highly organized classes of creatures to exist upon it; and I believe the simplest and the most truthful hypothesis that we can make on this subject is the oldfashioned one derived from final causes, that, according as the Creator arranged conditions of life on the globe physically suited to various creatures, He placed in succession on the globe, by His own will, creatures suitable to those conditions to enjoy them. Many modern writers have speculated on the manner in which this act of creation was accomplished; but in this speculation they have gone, as it appears to me, beyond the limits of human knowledge, for I believe it to be not only more reverent, but also, more in accordance with fact, to suppose that as the conditions of life upon the globe changed and improved, so as to render possible the existence of more highly organized groups of creatures, those creatures were placed there by the arbitrary will of their Creator.

APPENDIX (A).

PHYSICAL THEORIES OF SOLAR HEAT.

Newton believed the sun and fixed stars to owe their heat to a combustion similar to that of terrestrial fires, and to have the materials of their fire renovated from time to time by the agency of comets. The following passages from his "Opticks," and from the "Principia," show the views he held:—

"And are not the sun and fixed stars great earths vehemently hot, whose heat is conserved by the greatness of the bodies, and the mutual action and reaction between them, and the light which they emit, and whose parts are kept from fuming away, not only by their fixity, but also by the vast weight and density of the atmospheres incumbent upon them; and very strongly compressing them, and condensing the vapours and exhalations which arise from them? For if water be made warm in any pellucid vessel emptied of air, that water in the *vacuum* will bubble and boil as vehemently as it would in the open air in a vessel set upon the fire till it conceives a much greater heat. For the weight of the incumbent atmosphere keeps down the vapours, and hinders the water from boiling, till it grow much hotter than is requisite to make it boil *in vacuo*. Also a mixture of tin and lead being put upon a red hot iron *in vacuo* emits a fume and flame, but the same mixture in the open air, by reason of the incumbent atmosphere, does not so much as emit any fume which can be perceived by sight. In like manner the great weight of the atmosphere which lies upon the globe of the sun may hinder bodies there from rising up and going away from the sun in the form of vapours and fumes, unless by means of a far greater heat than that which on the surface of the earth would very easily turn them into vapours and fumes. And the same great weight may condense those vapours and exhalations as soon as they shall at any time begin to ascend from the sun, and make them presently fall back again into him, and by that action increase his heat much after the manner that in our earth the air increases the heat of a culinary fire. And the

same weight may hinder the globe of the sun from being diminished, unless by the emission of light, and a very small quantity of vapours and exhalations."—*Opticks*, book iii., Qu. 11, p. 318: London, 1730.

"Cometa, qui anno 1680 apparuit, minus distabat a Sole in perihelio suo quàm parte sextâ diametri Solis; et propter summam velocitatem in viciniâ illâ, et densitatem aliquam atmosphæræ Solis, resistentiam nonnullam sentire debuit, et aliquantulum retardari, et propiùs ad Solem accedere: et singulis revolutionibus accedendo ad Solem, incidet is tandem in corpus Solis. Sed et in aphelio ubi tardissimè movetur, aliquando per attractionem aliorum cometarum retardari potest, et subindè in Solem incidere. Sic etiam stellæ fixæ, quæ paulatim expirant in lucem et vapores, *cometis in ipsas incidentibus refici possunt, et novo alimento accensæ pro stellis novis haberi.* Hujus generis sunt stellæ fixæ, quæ subito apparent, et sub initio quàm maximè splendent, et subindè paulatim evanescunt."—*Principia*, lib. iii., prop. xlii.

Newton did not confine the office of comets merely to the renewing of the combustible materials of the sun; he believed that they also performed the duty of replenishing that part of our atmosphere on which organic life depends, which is undergoing a perpetual diminution, and which we now call oxygen:—

"Nam quemadmodum maria ad constitutionem Terræ hujus omnino requiruntur, idque ut ex iis per calorem Solis vapores copiosè satis excitentur, qui vel in nubes coacti decidant in pluviis, et Terram omnem ad procreationem vegetabilium irrigent et nutriant; vel in frigidis montium verticibus condensati (ut aliqui cum ratione philosophantur) decurrant in fontes et flumina: sic ad conservationem marium et humorum in planetis requiri videntur cometæ, ex quorum exhalationibus et vaporibus condensatis quicquid liquoris per vegetationem et putrefactionem consumitur et in Terram aridam convertitur, continuò suppleri et refici possit. Nam vegetabilia omnia ex liquoribus omninò crescunt, dein magnâ ex parte in Terram aridam per putrefactionem abeunt, et limus ex liquoribus putrefactis perpetuò decidit. Hinc moles Terræ aridæ in dies augetur, et liquores, nisi aliundè augmentum sumerent, perpetuò decrescere deberent, ac tandem deficere. *Porrò suspicor spiritum illum, qui aëris nostri pars minima est, sed subtilissima et optima, et ad rerum omnium vitam requiritur, ex cometis præcipuè venire.*"—*Principia*, lib. iii., prop. xli.

APPENDIX (B).

METEORIC THEORY OF THE SUN.

In the abstract of Professor Thomson's paper, published by the British Association, and in the Philosophical Magazine, the calculation of these limits is not given, and I cannot therefore state the principle on which it depends.

In a paper read before the Royal Society of Edinburgh, and published in their Transactions (1854), Professor Thomson gives the details of his improvement on Waterston's Meteoric Theory of Solar Heat, from which I have taken the following results:—

The quantity of meteorites falling upon the sun, requisite to produce the whole heat given out by him, is 3800 lbs. per square foot per annum, which quantity would add 60 feet per annum to the sun's radius, supposing the meteorites to have the sun's density, and would equal the mass of the earth in 47¾ years.

The following Table shows the time, during which each planet, if precipitated in a spiral path on the sun's surface, could keep up the present amount of solar radiation; and from this Table, it follows that all the planets taken together possess a *vis viva* equivalent to less than 50,000 years of solar radiation.

Table showing the equivalents of the Planetary Motions in Solar Heat.

	Heat of Gravitation, equal to solar emission for a period of—		Heat of Rotation, equal to solar emission for a period of —	
	Years.	Days.	Years.	Days.
Sun,	. . .	. . .	116	6
Mercury,	6	214	—	15
Venus,	83	227	—	99
Earth,	94	303	—	81
Mars,	12	252	—	7
Jupiter,	32,240	—	14	144
Saturn,	9650	—	2	127
Uranus,	1610	—	—	71
Neptune,	1890	—	—	—
Total,	**45,588** Years.		**133½** Years.	

APPENDIX (C).

THE GEOLOGICAL CALCULUS.

Although I have spoken somewhat disrespectfully of the Geological Calculus in my Lecture, yet I believe that the time during which organic life has existed on the earth is practically infinite, because it can be shown to be so great as to be inconceivable by beings of our limited intelligence.

The commencement of organic life on the globe cannot be placed further back than the time when the temperature of its polar regions was 122° F., at which degree of heat albumen coagulates. Instead, however, of considering the temperature of the polar regions, let us suppose the commencement of organic life to be the period when the temperature of the British Islands was 122° F., which was subsequent to the period when the polar regions had that temperature; and let us consider the London clay tertiary epoch, during which tropical Mollusks inhabited the seas of Britain, as the close of the period whose duration we wish to calculate; when, judging by the analogy of similar Mollusks now living, the British Islands cannot be supposed to have had a mean temperature much below 77° F., which is the mean temperature of the regions inhabited by the living Nautilus. It is required to calculate the time necessary for the mean temperature of Britain to fall, in consequence of the cooling of the earth, from 122° F. to 77° F.

The present mean temperature of Britain is 50° F., which there is good reason to believe is the temperature, corresponding to our latitudes, of thermal equilibrium between the heat radiated by the earth and received by it from the sun, and from stellar space. In fact, Laplace has shown by the following considerations, that we must regard the earth as having at present arrived at a condition of perfect thermal equilibrium.

If we suppose the earth to lose an appreciable amount of heat by radiation, this loss of heat would cause a contraction of the materials composing it, and, by diminishing the moment of inertia, shorten the length of the day, which, if we suppose diminished by

the $\frac{1}{100}$th part of a second, the length of the century would be altered by 365.25 secs.; in which time the moon describes an arc of 534′.6; this quantity would therefore appear in the moon's mean secular motion; but it is shown from Ptolemy's tables of Hipparchus' observations and his own observations of the lunar eclipses that such an error is inadmissible. Hence we are entitled to conclude that since the time of Hipparchus the length of the day has not shortened by the hundredth part of a second. Again, if we assume the expansibility of the materials composing the earth to be $\frac{1}{100000}$ for 1° C. i. e., the expansibility of glass, it can be proved that since the time of Hipparchus the secular heat of the earth has not diminished by the $\frac{1}{170}$th part of 1° C.

Considering, then, 50° F. as the equilibrium temperature of the British Islands, it is required to calculate the time required for the earth to cool down, in our latitudes, from 122° F. to 77° F.; that is, from the temperature of coagulation of albumen to that at which the existing Nautilus flourishes.

The foregoing temperatures, expressed in Centigrade degrees, are as follow:—

122° F. = 50° C.
77 F. = 25 C.
50 F. = 10 C.

Hence, at the commencement and end of the epoch under consideration, the excess of temperature above that of equilibrium, is 40° C. and 15° C. respectively.

It is well known that the time of cooling of a heated body exposed in vacuo is given by the formula*

$$x = \frac{1}{N \log. a} \times \log\left(\frac{a^t - 1}{a^t}\right) + \text{Const.} \qquad (1)$$

where—

x = time elapsed from the origin;
N = a constant depending on the surrounding medium;
a = 1.0077;
t = the excess of the temperature above that of thermal equilibrium in Centigrade degrees.

Helmholtz has computed, from the experiments of Bischof on basalt, that it would require 350 millions of years for our earth to cool from 2000° to 200° Centigrade, in excess of the temperature of thermal equilibrium.

Assuming this datum, it is easy to prove from equation (1) that the time of cooling from 40° C. to 15° C. excess above the equilibrium temperature is

* Peclet, "Traité de Physique," vol. i., p 430: 8vo, Paris, 1847.

$$\left.\begin{array}{l}\text{Time of cooling from}\\ \text{122° F. to 77° F.}\\ \text{expressed in mil-}\\ \text{lions of years}\end{array}\right\} = 350 \times \frac{\log.\left(\dfrac{a^{15}-1}{a^{15}} \times \dfrac{a^{40}}{a^{40}-1}\right)}{\log.\left(\dfrac{a^{200}-1}{a^{200}} \times \dfrac{a^{2000}}{a^{2000}-1}\right)} \quad (2)$$

Substituting in this equation for a its value 1.0077, we find

$$\log.\left(\frac{a^{15}-1}{a^{15}} \times \frac{a^{40}}{a^{40}-1}\right) = \bar{1}.6142133;$$

and

$$\log.\left(\frac{a^{200}-1}{a^{200}} \times \frac{a^{2000}}{a^{2000}-1}\right) = \log.\left(\frac{a^{200}-1}{a^{200}}\right) = \bar{1}.8945072.$$

Hence the time is

$$350 \times \frac{3857867}{1054928} = 1280 \text{ millions of years.}$$

If we calculate the time of cooling from 212° F. (the temperature of boiling water, at which the sea was condensed, and when the formation of strata by aqueous action became possible) to 122° F. (the temperature of coagulation of albumen, at which organic life becomes possible), we find—

$$\left.\begin{array}{l}\text{Time of cooling from}\\ \text{212° F. to 122° F.}\\ \text{expressed in mil-}\\ \text{lions of years}\end{array}\right\} = 350 \times \frac{\log.\left(\dfrac{a^{40}-1}{a^{40}} \times \dfrac{a^{100}}{a^{100}-1}\right)}{\log.\left(\dfrac{a^{200}-1}{a^{200}}\right)}$$

$$= 350 \times \frac{3068865}{1054928} = 1018 \text{ millions of years.}$$

The periods of time indicated by the foregoing calculations for the deposition of the Zoic and Eozoic strata are practically infinite, for they are inconceivable by us.

Vast as the period of 1280 million of years must appear to us, yet the globe was habitable, in parts at least, for a longer period; for the polar temperature would have admitted of the existence of animal life before it was possible in Britain; and it is also highly probable that the rate of cooling of the earth was slower than is here assumed; for whatever reason there is to believe in a former higher temperature of the earth, there is the same reason to believe in a former higher temperature of the sun, the effect of which would be to retard the cooling of the earth beyond the period assigned by the preceding calculation, in which the solar temperature is assumed to be constant.

It would be useless to attempt to calculate the period during which the temperature of Britain fell from 77° F. to 50° F., as there is reason to believe that, in approaching the condition of thermal equilibrium, the heat of our climates became much influenced by the distribution of land and water. It is quite certain, at least, that the present temperature of Britain admits of being much lowered by such causes, and it is probable that it might be also raised, though not to anything like the same extent.

If we compare 1280 millions of years with the thickness of British and western European Zoic rocks, viz. 18.385 geographical miles, we shall find that each foot of rock corresponds to 11,604 years of time. It would be very absurd to suppose that it requires 11,000 years to deposit one foot of mud, for which one year would be a sufficient time; but it is not at all irrational, from what we know of existing causes, to suppose that not more than one foot in every 11,000 deposited is represented in our strata, for the causes that deposit sediment are also continually removing it, and it is quite possible that only $\frac{1}{11604}$th part of the geological record is preserved for our study.

Thus the stony tables that contain the history of the earth, though written with the finger of God, are broken and mutilated by the lapse of time, and can never give up to even our most diligent research all the secrets they once contained.

LECTURE V.

CURVE OF RATE OF PRODUCTION—CURVE OF ZOOLOGICAL IMPORTANCE—CURVE OF CHRONOLOGICAL DEVELOPEMENT—ARISTOTLE'S CLASSIFICATION OF ANIMALS—CLASSIFICATION OF LINNÆUS—CLASSIFICATION OF CUVIER—ANIMAL SUBKINGDOMS—DEFINITIONS.

IN Lecture IV. we considered the relation between the thickness of rocks and the developement of organic life during the time those rocks were forming; and we came to the conclusion that the best estimate we can form of the lapse of time in geology is that founded on the measurement of the thickness of rocks, so that a mile in thickness of rocks of a given character, suppose sandstones or limestones, will probably represent the same amount of time, whether it be found in the older or in the newer strata; but as we pass from the older to the newer rocks, we find that a given thickness will represent in the newer a much larger number of species of animals than it represents in the older rocks, though not a greater number of individuals; a fact which shows that the rate of production of animals increased as the world grew older.

If you imagine a curve described, such that the horizontal line or axis of abscissæ shall denote time, and the vertical ordinates denote the number of species per mile thickness of rock, you will have a curve which I call the curve of the rate of production. In the annexed Diagram, No. I., I have exhibited this curve, roughly drawn from the accom-

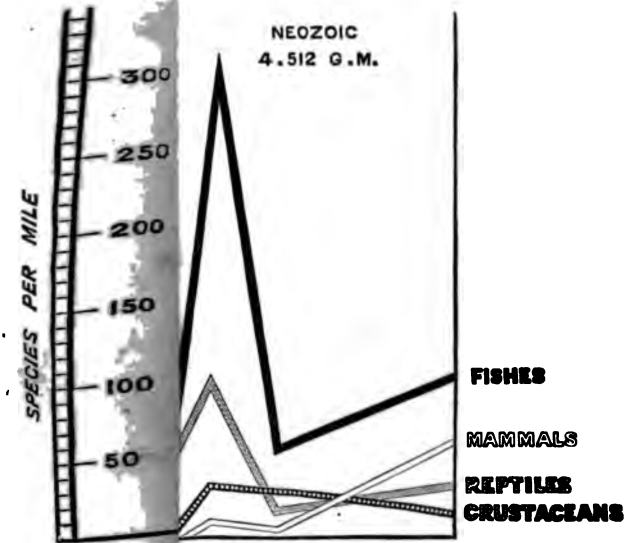
panying Table of British fossil mammals, reptiles, fishes, and crustaceans.

You observe that the curves sometimes rise gradually till they reach a maximum, then fall, then rise again, then fall and rise again, and so on. That has happened, for example, with the curve of the crustaceans. The rate of production of crustaceans has three times reached a maximum, and twice reached a minimum. Therefore we may say that the creative force producing crustaceans has had three maxima, and two minima, in the history of the world. Such curves as these would, if carefully constructed, and if we had sufficient data, give an accurate idea of the relation that exists between the rate of deposition of stratified rocks and the progress of life on the globe.

In discussing the question of the relative proportion in which animals of different kinds or groups existed at different ages of the world, we must make use of a curve of a different kind. We shall use for that purpose one which I call the curve of zoological importance, and which is shown for mammals, reptiles, fishes, and crustaceans in Diagram, No. II.

The base line of the curve is still time; but the ordinate, instead of being the number of species per mile, is now the proportion per cent. which the animals bore to the whole number of all species living at the time. As this curve increases, the animals belonging to it bear a higher and higher proportion to the whole of the animals then living, and *vice versâ*. To form this curve, we take for each given formation of the earth's history the total number of British species of animals then living, as shown in the accompanying Table. We

To face page 104.



MAMMALS.

	Jurassic.	Cretaceous.	Tertiary.
Crusta	27	23	15
Fishes,	270	50	118
Reptil	88	12	32
Mamma	7	—	34
	Neozoic.		

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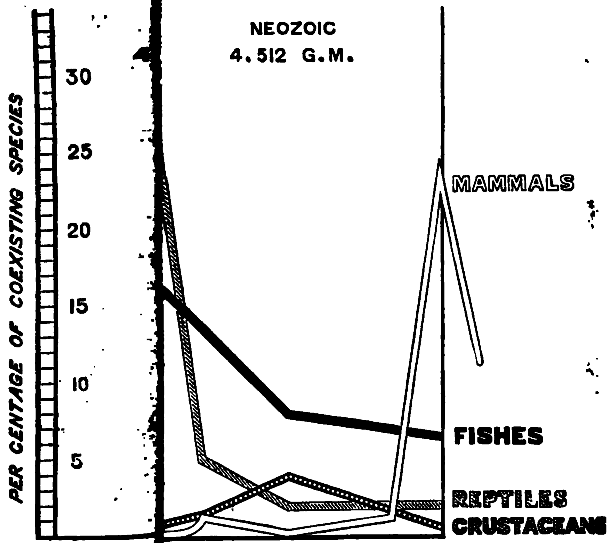

ND MAMMALS.

CLAS	Cretaceous.	Tertiary.	Post Tertiary.
CRUSTACE	3	1	4
FISHES,	7	7	—
REPTILES,	2	2	—
MAMMALS,	—	2	22
	ozoic.		Ontozoic.

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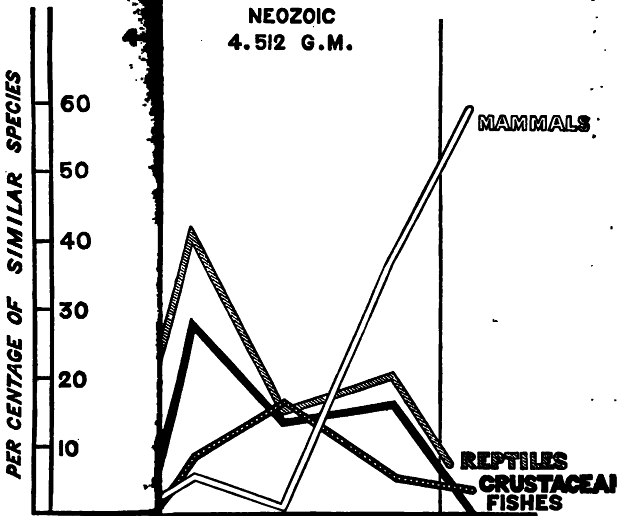

ND MAMMALS.

CLASS	Cretaceous.	Tertiary.	Post Tertiary.
Crustacea	15	5	3
Fishes, .	13	16	—
Reptiles,	14	20	—
Mammals,	—	35	60
	zoic.		Ontozoic.

then take each group of animals, separately, and find what proportion the number of species in each bears to the total number of species in the then existing creation; and in this manner we find curves such as the above. In the crustaceans the curve of zoological importance reaches three maxima and two minima, as before, showing some striking resemblances to the curve representing the rate of creation; but we find also very striking differences with regard to the relative position of the maxima, to which I shall not direct your attention further at present, for I shall have occasion to return again to both curves in the course of these lectures.

In addition to the curves that exhibit the Rate of Production, and Zoological Importance of Fossils, a third curve may be constructed which shows their developement. This curve, and the Table of British Fossils from which it is formed, are contained in Diagram, No. III., for mammals, reptiles, fishes, and crustaceans.

The base line is time, as before, and the ordinates are the percentages which the fossils of a given kind, at any epoch, bear to all fossils of the same kind, of all epochs.

By this curve, the developement, or chronological importance of each group, compared with itself, is well shown. The conclusions that follow from it are similar to those already deduced from the other curves.

These curves, and the Tables which are appended to them, are deduced from Morris's "Catalogue of British Fossils" (1854), a work of great and permanent value, and the result of the labour of a life.

The numbers used by me are contained in the following Table:—

TABLE SHOWING THE TOTAL NUMBER OF SPECIES OF CRUSTACEANS, FISHES, REPTILES, MAMMALS, AND OTHER ANIMALS, HITHERTO FOUND FOSSIL IN THE BRITISH ISLANDS (854).

	Lower Palæozoic.		Upper Palæozoic.			Neozoic.				Ontozoic.	
—	Lower Silurian (including Cambrian).	Upper Silurian.	Devonian.	Carboniferous.	Permian.	Triassic.	Jurassic.	Cretaceous.	Tertiary.	Post Tertiary.	TOTAL.
Crustaceans, ...	110	37	12	36	11	1	21	44	15	10	**297**
Fishes, ...	—	7	94	179	16	21	207	94	118	—	**736**
Reptiles, ...	—	—	1	1	3	33	68	23	32	—	**161**
Mammals, ...	—	—	—	—	—	—	5	—	34	57	**96**
Other Fossils, ...	354	419	321	1012	104	88	1285	1165	1320	187	**6255**
TOTAL, ...	**464**	**463**	**428**	**1228**	**134**	**143**	**1586**	**1326**	**1519**	**254**	**7545**
	927		**1790**			**4574**					
	Malacozoic.		Ichthyozoic.			Saurozoic.				Mastozoic.	

We have now to consider the animal kingdom in general, the classification that has been made of it, and the use that geologists make of such classification. Strictly speaking, we ought to consider the vegetable as well as the animal kingdom; but geology has thrown so little light upon the study of plants, in consequence of their necessarily imperfect preservation in the fossil state, that much less is known of this subject than of the other. I shall therefore at present confine myself altogether to the animal kingdom; and will make some remarks on the vegetable kingdom when I come to speak of the Carboniferous period.

From our definition of a fossil as an organic remain or trace of an organic creature found in a rock, it is evident that nothing but the hard parts of animals can be preserved, and that therefore the geologist is placed in a position of peculiar difficulty in attempting to study fossil zoology. The recent zoologist can study the soft parts of an animal as well as the hard parts. He can dissect; he can use the microscope; compare the parts of the animal with the corresponding parts of other animals resembling it, and so obtain information of the most precious kind, from which the palæontologist is completely and totally excluded. The palæontologist must confine his observations altogether to the skeletons, the shells, and the hard parts of animals, and, in a few rare cases, to natural casts of the soft parts of either their external forms, or, as sometimes happens, of the interior of their intestines, as in the case of coprolites. It is therefore evident that palæontology must borrow largely from zoology; it must borrow its classification from zoology; and, on the other hand, it is no exaggeration to say that

the science of palæontology has returned to zoology tenfold all that it has borrowed from it. Many of the most important speculations in zoology have been suggested by the light that the study of extinct animals has thrown upon the recent creation. Cuvier admits his obligations to the study of fossil remains in many ways, as having helped him largely in his scientific and philosophical classifications; for it has been found that the extinct animals, while they nowhere form exceptions to our classifications, fill up great gaps—lacunæ—that existed in the classifications, and which we were at a loss to know in what way we should interpret.

Before, therefore, we study fossils, it is necessary for us to form a distinct idea of what zoological classification we will adopt; and I shall now give you a sketch—necessarily very brief and rapid—of the most celebrated classifications that have been brought forward by naturalists. Those that I shall notice are, the classifications of Aristotle, of Pliny, of Linnæus, of Cuvier, and of Lamarck.

Aristotle was the first person that studied animals systematically, so far as we have any record in ancient writings; unless, indeed, we except Moses* and King Solomon, the former of whom accurately distinguished the Ruminants from the Pachyderms and Rodents;† and the latter of whom certainly studied both botany and zoology, because we are told that "he spake of trees, from the cedar-tree that is in Lebanon even unto the hyssop that springeth out of the wall; he spake also of beasts, and of fowl, and of creeping things, and of fishes."‡ But though

* *Vide* Appendix (A). † Lev. xi. 3-7; Deut. xiv. 4-8.
‡ 1 Kings, iv. 33.

some writers think that Solomon even wrote on these subjects, it is quite certain that in the sacred Scriptures no record has come down to us of any knowledge of his of that kind.

Aristotle divides animals into those with blood and those without blood,—the *ζῷα ἔναιμα* and the *ζῷα ἄναιμα*. He considered blood to be necessarily red, and his classification of animals with and without blood was identical with the modern classification of animals into vertebrate and invertebrate. He was well aware that this property of having blood or not having blood was intimately connected with the property of having or not having a back bone, for he says "that all animals that have blood have also a back bone either osseous or semiosseous."

The vertebrate animals are subdivided by Aristotle into those having bone proper, spinous bone, and cartilage.

This classification was founded upon anatomical distinctions, and was therefore scientific and not artificial, and the other parts of his system were based upon physiological distinctions of the highest importance; for he considers animals in relation to the embryo from which they spring, as viviparous, oviparous, and vermiparous, and was well aware of the existence of an ovo-viviparous class, including the cartilaginous fishes; for he says that, "of viviparous animals, some (as the cartilaginous fishes) produce within their bodies an egg, and others (as man and the horse) produce within them an animal."

Aristotle's classification may be thus tabulated:—

ARISTOTLE'S CLASSIFICATION OF ANIMALS.*

I. Animals with red blood, possessing a vertebral back bone. (τὰ ζῷα ἔναιμα, ῥάχιν ἔχοντα).	1. Osseous. (ὀστώδη).	a. Viviparous. (ζωοτόκα). b. Oviparous. (ᾠοτόκα).
	2. Semiosseous. (ἀκανθώδη).	Oviparous. (ᾠοτόκα).
	3. Cartilaginous. (χονδράκανθα).	Ovo-viviparous. (ζωοτόκα, ἐν αὑτοῖς ᾠοτοκοῦντα).
II. Animals without red blood; destitute of a vertebral back bone. (τὰ ζῷα ἄναιμα, μὴ ῥάχιν ἔχοντα).		1. Oviparous. (ᾠοτόκα). 2. Vermiparous. (σκωληκοτόκα).

The celebrated Pliny, who gave our next classification of animals, was not as scientific in his tastes as Aristotle, whose system may be considered as founded, in the main, upon anatomical and physiological points of difference, and therefore highly philosophical. Pliny's classification was such as you might expect from the tendencies of the Roman mind; it was one of direct and easy application. It classified animals according as they lived on the ground, in the water, or in the air. He called all animals Terrestrial, Aquatic, or Volatile, and formed a distinct class for those animals, such as insects, that do not belong to any element exclusively:—

PLINY'S CLASSIFICATION OF ANIMALS.

I. Animalia terrestria.
II. Animalia aquatilia.
III. Volucres.
IV. Animalia insecta.

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* *Vide* Appendix (B).

Zoology remained in this condition, with these two classifications, until the time of Linnæus, who was the creator of modern natural science; and the publication of his great work, the "Systema Naturæ," laid the foundation of everything that has been done by the moderns in this branch of knowledge. He grasped the whole creation in his comprehensive mind in this great work, dividing it into mineral, vegetable, and animal kingdoms, and in the following passage gives us a summary of his definition of these three great kingdoms:—

"Naturalia sunt corpora cuncta Creatoris manu composita, corticem Telluris constituentia, in Regna Naturæ tria divisa, quorum limites concurrunt in Lithophytis:—

"*Lapides* corpora congesta, nec viva nec sentientia.

"*Vegetabilia* corpora organisata et viva, non sentientia.

"*Animalia* corpora organisata et viva et sentientia, sponteque se moventia.

"Regna Naturæ, planetam Telluris constituentia, ideoque tria sunt:—

"*Lapideum* rude inhabitat interiora; a salibus in terris generatur; temere miscetur; casu modificatur.

"*Vegetabile* virens superficiem vestit, radiculis bibulis terrena haurit; foliis obvolitantibus ætherea respirat; calidâ metamorphosi declaratur in festivales nuptias, generantes dispergenda intra præscriptas stationes semina.

"*Animale* sentiens exteriora ornat; voluntarie movetur; respirat; ova generat; pellitur iratâ Fame, lætâ Venere, mœstoque Dolore; prædando coercet vegetabilia populares que, ut omnium pro-

portio perennet."—*Systema Naturæ*, tom. i., pp. 4, 5, ed. xiii.

The animal kingdom he divides into six groups, which are founded, like those of Aristotle, strictly upon comparative anatomical distinctions, the only solid basis on which any classification of the animal kingdom can rest. His classification of these groups is the following:—Mammals, Birds, Amphibians, Fishes, Insects, and Worms.* These six groups are themselves subdivisions of three, viz.:—

1. Mammals and Birds, having a heart with two ventricles and two auricles, and warm red blood; and they are divided from each other by the mammals being viviparous, and the birds oviparous.

2. Amphibians and Fishes, which are grouped together by the anatomical peculiarity of having a heart with one ventricle and one auricle, and cold red blood; and are distinguished from each other by the Amphibians having lungs, and the Fishes having gills.

3. The fifth and sixth groups are Insects and Worms, which are united by the common quality of having a heart with one ventricle and no auricle, and cold white quasi blood; while the insects are distinguished from the worms by their having *antennæ*, and the worms having *tentacula*.

The errors which modern anatomists have pointed out in this classification of Linnæus are chiefly three. The first is with respect to the Amphibians, which have two auricles, whereas Linnæus considered that they had only one ventricle and one auricle. In the second place, some of his Insecta have no hearts at

* *Vide* Appendix (C).

all; and therefore in their case the heart cannot be made the ground of classification. Thirdly, many of his Worms have an auricle as well as a ventricle, whereas Linnæus considered that they had only one ventricle and no auricle. It is easy, however, for us, with our present knowledge, to find fault with this classification, which at the time it was made was a most astonishing advance beyond the knowledge that previously existed. Many systematic writers on zoology consider that in calling Amphibians, Reptiles, we have changed the name for the worse.

The next important step in classification was made by Cuvier, who divided all animals, as Aristotle had done, into Vertebrate and Invertebrate; and the Invertebrate he divided into Mollusca, Articulata, and Radiata as follows:—

CUVIER'S CLASSIFICATION OF THE ANIMAL KINGDOM.*

1. Vertebrata.
2. Mollusca.
3. Articulata
4. Radiata, or Zoophyta.

Many naturalists are now of opinion that Cuvier's fourfold division should be modified by dividing his fourth group, *Radiata*, into three, removing from it the Echinoderms, which, according to some, should be added to his third group, *Articulata*, while, according to others, they are of sufficient importance to form a subkingdom of their own.

Lamarck proposed to divide the Invertebrate portion of the animal kingdom into ten groups, consisting of *sensitive* and *apathic* animals, as dis-

* *Vide* Appendix (D).

tinguished from the Vertebrata, which are called *intelligent*:—

LAMARCK'S CLASSIFICATION OF INVERTEBRATA *

Sensitive.		*Apathic.*
1. Insecta.	4. Annelida.	7. Vermes.
2. Arachnida.	5. Cirripeda.	8. Radiata.
3. Crustacea.	6. Mollusca.	9. Polypi.
		10. Infusoria.

The following are the Subkingdoms which we shall adopt throughout this course of Lectures:—

SUBKINGDOMS OF THE ANIMAL KINGDOM.

I.	SPONDYLOZOA σπονδυλοζῶα	=	VERTEBRATA.
II.	ENTOMOZOA ἐντομοζῶα	=	ARTICULATA, OR ANNULOSA.
III.	MALACOZOA μαλακοζῶα	=	MOLLUSCA.
IV.	ECHINOZOA ἐχινοζῶα	=	ECHINODERMATA.
V.	CŒLENTEROZOA κοιλεντεροζῶα	=	CŒLENTERA.
VI.	PROTOZOA πρωτοζῶα	=	PROTOZOA.

I shall conclude this lecture by a few words as to the definition of these six groups. It is the opinion of some writers on zoology that the whole animal kingdom forms a continued line of existence; that we can pass from man, the highest creature in that kingdom, to the lowest form of sponge, by a continuous series of beings. That idea derived at first great confirmation from the discoveries of

* "Histoire Naturelle des Animaux sans Vertèbres," vol. i. p. 313. Paris: 1835.

geologists, because many of the missing links in this long chain were thought to have been found in a fossil condition. Cuvier's celebrated discoveries among the mammals of Montmartre and other localities filled up so many important gaps, and connected together so many living animals which before were separated from each other, that they led some naturalists into the mistake of considering the whole animal kingdom as a continuous line of organic beings; and some of the most brilliant of speculators have adopted this idea, which is very attractive from its symmetry and simplicity. But it is open to the objection that it is not a true representation of nature. We shall therefore rather, with Cuvier and others, regard the animal kingdom as referred to certain types, which are each characterized by its own plan of structure; the animals within the limits of the same type being more closely connected with each other than with the animals of the other types.

These six Subkingdoms represent six distinct types; but we are not to suppose that a vertebrate animal, as such, is always superior in intelligence, in sensitive and general endowments, to an annulose animal, although as a class the *Vertebrata* are superior to the *Annulosa*. We can produce imperfect and low specimens of vertebrate animals, that are inferior in almost every quality to the more highly organized, not only of the *Annulosa*, but even of the *Mollusca*. Therefore you are to consider that in these six groups the lowest of each type may be lower in the scale of creation and intelligence than the highest of the type immediately below it; and thus we are to regard the animal kingdom rather as six distinct cycles than as one descending series, each cycle

having its intelligent and well-developed members, and also its inferior and imperfect specimens. To suppose each member of a type to be superior to all of the types below him, would be about the same thing as to say that if we compared the Europeans with the Africans, every European must be superior in intelligence to every African. Now, we know that this is not the case. There are thousands of persons amongst us, perhaps some now listening to me, who are inferior in many qualities, not only physical, but moral and intellectual, to intelligent and well-endowed Africans who have received no such advantages of education as the Europeans have. But of course, as a class the Europeans are superior to the Africans. And so with animals.

A great number of definitions have been given of these six groups. I shall adopt as the best suited to our purpose, as geologists, definitions which exclude anatomical peculiarities of the soft parts, which cannot be inferred from the structure of the hard parts preserved as fossils.

The *Spondylozoa*, or the Vertebrate animals, with which we commence, are doubly symmetrical; and their nervous system, composed of a brain and spinal chord, is protected by a bony skeleton, the parts of which form a series of homologous segments disposed along the entire length of the body. Their limbs, which also contain an internal skeleton, never exceed four in number, and are always turned away from the nervous axis.

The *Entomozoa*, or Annulose animals, are characterized by a nervous system, composed of several pairs of ganglia connected by commissures, and forming a ventral nervous chord, towards which the limbs are turned; by the absence of an internal bony

skeleton; by their body being frequently protected by a hardened skin, forming a succession of serially homologous parts, articulated to one another, and bearing the jointed limbs.

In the *Malacozoa*, or Mollusks, the body is non-segmented, and destitute of true limbs. Their nervous system includes not more than three principal pairs of ganglia. They have sometimes a soft skin, but are frequently protected by shells.

The *Echinozoa* possess a tegumentary skeleton, usually furnished with spines, and exhibiting definite lines, or ambulacra, along which the so-called "feet" are protruded. These feet receive the lateral processes of peculiar longitudinal canals issuing from a ring around the gullet, and forming part of the ambulacral vascular system. The nervous system consists of a central chord lying close to the ambulacral vascular ring, and giving off five primary filaments, which radiate along the principal regions of the body.

The *Cœlenterozoa* are animals with hollow insides, that is, their digestive canal freely communicates with, or forms part of, the general cavity of the body. A nervous system is wanting in most. The corals, which often appear to present a radiate arrangement of their parts, belong to this sub-kingdom.

The last group of animals are the *Protozoa*, which are characterized by their excessively simple structure, by the absence of a well defined nutrient cavity, and by their apparent general indifference to shape or symmetry of any kind.

APPENDIX (A).

CLASSIFICATION OF ANIMALS AMONG THE HEBREWS.

A FOURFOLD division of the animal kingdom was formally made by Moses in Deuteronomy, iv. 17, 18, which is repeated in the account of the wisdom of Solomon, quoted in the Lecture, and frequently referred to in other passages of the Old Testament Scriptures.

It is as follows :—

I.—בְּהֵמָה (*Behemah*); LXX. κτῆνος; Vulg. *jumentum* : ***Mammals***, especially the larger kinds, including the Carnivora, such as the lion (Prov. xxx. 30); also the hippopotamus (Job xl. 15), as well as domestic cattle; it is opposed to birds and reptiles.

II.—צִפּוֹר or עוֹף (*Tsippor* or *Gnuf*); LXX. ὄρνεον πτερωτὸν, or πετεινὸν; Vulg. *avis*, or *volatile ; Birds*, so called from their singing and flying. The first term is more applicable to the smaller birds (the root being צָפַר *fistulavit*); the latter is the more general.

III.—רֶמֶשׂ (*Remes*); LXX. ἑρπετόν; Vulg. *reptile ; **Reptiles***, including all animals that creep or crawl upon the ground, insects, worms, &c., as well as reptiles proper.

IV.—דָּג (*Dag*); LXX. ἰχθύς; Vulg. *piscis ; Fishes*, not including the Cetacea, for which a distinct Hebrew word was used (תַּנִּין).

APPENDIX (B).

ARISTOTLE'S CLASSIFICATION.

THE following are the principal passages from which I have collected the summary of the classification of Aristotle, contained in the Lecture:—

Πρὸς δὲ τούτοις τὰ μὲν [ζῷα] ἔναιμα τυγχάνει ὄντα, οἷον ἄνθρωπος καὶ ἵππος καὶ πάνθ' ὅσα ἢ ἄποδά ἐστι τέλεα ὄντα ἢ δίποδα ἢ τετράποδα· τὰ δὲ [ζῷα] ἄναιμα, οἷον μέλιττα καὶ σφὴξ καὶ τῶν θαλαττίων σηπία καὶ κάραβος καὶ πανθ' ὅσα πλείους πόδας ἔχει τεττάρων.

καὶ τὰ μὲν ζῳοτόκα τὰ δὲ ᾠοτόκα τὰ δὲ σκωληκοτόκα, ζῳοτόκα μὲν οἷον ἄνθρωπος καὶ ἵππος καὶ φώκη καὶ τὰ ἄλλα ὅσα ἔχει τρίχας, καὶ τῶν ἐνύδρων τὰ κητώδη, οἷον δελφίς, καὶ τὰ καλούμενα σελάχη. . . . . . . καλεῖται δ' ᾠὸν μὲν τῶν κυημάτων τῶν τελείων, ἐξ οὗ γίγνεται τὸ γινόμενον ζῷον, ἐκ μορίου τὴν ἀρχήν, τὸ δ' ἄλλο τροφὴ τῷ γινομένῳ ἐστίν· σκώληξ δ' ἐστὶν ἐξ οὗ ὅλου ὅλον γίνεται τὸ ζῷον, διαρθρουμένου καὶ αὐξανομένου τοῦ κυήματος. τὰ μὲν οὖν ἐν αὑτοῖς ᾠοτοκεῖ τῶν ζῳοτόκων, οἷον τὰ σελάχη, τὰ δὲ ζῳοτοκεῖ ἐν αὑτοῖς, οἷον ἄνθρωπος καὶ ἵππος· εἰς δὲ τὸ φανερὸν τῶν μὲν τελεωθέντος τοῦ κυήματος ζῷον ἐξέρχεται, τῶν δ' ᾠόν, τῶν δὲ σκώληξ.—*Hist. Animal.* lib. i. ch. 4.

ἀρχὴ δὲ ἡ ῥάχις ἐστὶν ἐν πᾶσι τοῖς ἔχουσιν ὀστᾶ. σύγκειται δ' ἡ ῥάχις ἐκ σφονδύλων, τείνει δ' ἀπὸ τῆς κεφαλῆς μέχρι πρὸς τὰ ἰσχία. οἱ μὲν οὖν σφόνδυλοι πάντες τετρημένοι εἰσίν, ἄνω δὲ τὸ τῆς κεφαλῆς ὀστοῦν συνεχές ἐστι τοῖς ἐσχάτοις σφονδύλοις, ὃ καλεῖται κρανίον . . . . ἔχει καὶ ὁ δελφὶς ὀστᾶ, ἀλλ' οὐκ ἄκανθαν. . . . . οἷον ἐν τοῖς ἰχθύσι· τούτων γὰρ τὰ μὲν ζῳοτοκοῦντα χονδράκανθα ἐστιν, οἷον τὰ καλούμενα σελάχη, τὰ δ' ᾠοτοκοῦντα ἄκανθαν ἔχει, ἥ ἐστιν ὥσπερ τοῖς τετράποσιν ἡ ῥάχις. . . . . . ὁμοίως δὲ καὶ ὁ ὄφις ἔχει τοῖς ἰχθύσιν· ἀκανθώδης γὰρ ἡ ῥάχις αὐτοῦ ἐστίν. τὰ δὲ τῶν τετραπόδων μὲν ᾠοτοκούντων δὲ τῶν μὲν μειζόνων ὀστωδέστερα ἐστι, τῶν δ' ἐλαττόνων ἀκανθωδέστερα. πάντα δὲ τὰ ζῷα ὅσα ἔναιμά ἐστιν, ἔχει ῥάχιν ἢ ὀστώδη ἢ ακανθώδη.—*Hist. Animal.* lib. iii. ch. 7.

APPENDIX (C).

LINNÆUS' CLASSIFICATION OF ANIMALS.

Divisio naturalis Animalium ab interna Structura indicatur :—

A. Cor biloculare, biauritum; *Sanguine* calido, rubro	viviparis, . . .	I. *Mammalibus.*
	oviparis, . . .	II. *Avibus.*
B. Cor uniloculare, uniauritum; *Sanguine* frigido, rubro,	pulmone arbitrario, . .	III. *Amphibiis.*
	branchiis externis,. . .	IV. *Piscibus.*
C. Cor uniloculare, inauritum; *Sanie* frigida, albida,	antennatis, . .	V. *Insectis.*
	tentaculatis, . .	VI. *Vermibus.*

I. Mammalia.

Cor biloculare, biauritum; *Sanguine* calido, rubro.
Pulmones respirantes reciproce.
Maxillæ incumbentes, tectæ; *Dentibus* intrusis plerisque.
Penis intrans viviparas, lactiferas.
Sensus : Lingua; Oculi; Aures; Papillæ.
Tegmenta : Pili, pauci indicis, parcissimi aquaticis.
Fulcra : Pedes quatuor, exceptis mere aquaticis, *in quibus pedes posteriores plane deficiunt.* Cauda *plerisque.*

II. Aves.

Cor biloculare, biauritum: *Sanguine* calido, rubro.
Pulmones respirantes reciproce.
Maxillæ incumbentes, nudæ, exsertæ, edentulæ.
Penis subintrans absque scroto oviparas crusta calcarea.
Sensus : Lingua, Nares, Oculi, Aures absque auriculis.
Tegmenta : Pennæ incumbentes, imbricatæ.
Fulcra : Pedes bini. Alæ binæ. *Uropygium* cordatum.

III. Amphibia.

Cor uniloculare, uniauritum; *Sanguine* frigido, rubro.
Pulmones spirantes arbitrarie.
Maxillæ incumbentes.
Penes (*multis*) bini. Ova *plerisque* membranacea.
Sensus: Lingua, Nares, Oculi, Aures.
Tegmenta cutacea nuda.
Fulcra varia variis, quibusdam nulla.

IV. Pisces.

Cor uniloculare, uniauritum; *Sanguine* frigido, rubro.
Branchiæ extus comprimendæ.
Maxillæ incumbentes.
Penes (*plerisque*) nulli. Ova absque albumine.
Sensus: Lingua, Nares? Oculi, Aures.
Tegmenta: Squamæ imbricatæ.
Fulcra: Pinnæ natatoriæ.

V. Insecta.

Cor uniloculare, uniauritum; *Sanie* frigida.
Spiracula: Pori laterales corporis.
Maxillæ laterales.
Penes intrantes.
Sensus: Lingua, Oculi, Antennæ in capite absque cerebro, non Aures, Nares.
Tegmenta: Cataphracta cute ossea sustentante.
Fulcra: Pedes, quibusdam Alæ.

VI. Vermes.

Cor (*plerisque*) uniloculare, inauritum; *Sanie* frigida.
Spiracula obscura.
Maxillæ multifariæ; variæ variis.
Penes varii Hermaphroditis, Androgynis.
Sensus: Tentacula. Oculi (*plerisque*). Cerebrum nullum, non aures, nec Nares.
Tegmenta calcarea aut nulla, nisi Spinæ.
Fulcra: nulli Pedes aut Pinnæ.

APPENDIX (D).

CUVIER'S CLASSIFICATION OF ANIMALS.

I.—ANIMALIA VERTEBRATA.

ILS ont tous le sang rouge, un cœur musculaire; une bouche à deux mâchoires placées l'une au dessus ou audevant de l'autre, des organes distincts pour la vue, pour l'ouïe, pour l'odorat et pour le goût, placés dans les cavités de la face; jamais plus de quatre membres; des sexes toujours séparés, et une distribution très semblable des masses médullaires et des principales branches du système nerveux.

II.—ANIMALIA MOLLUSCA.

Dans le deuxième forme, il n'y a point de squelette; les muscles sont attachés seulement à la peau, qui forme une enveloppe molle, contractile en divers sens, dans lequelle s'engendrent, en beaucoup d'espèces, des plaques pierreuses, appelées coquilles, dont la position et la production sont analogues à celles des corps muqueux; le système nerveux est avec les viscères dans cette enveloppe générale, et se compose de plusieurs masses éparses, reunies par des filets nerveux, et donc les principales, placées sur l'œsophage, portent le nom de cerveau. Des quatres sens propres, on ne distingue plus que les organes de celui de goût et de celui de la vue; encore ces derniers manquent-ils souvent. Une seule famille montre des organes de l'ouïe. Du reste, il y a toujours un système complet de circulation, et des organes particuliers pour la respiration. Ceux de la digestion et des sécrétions sont à-peu-pres aussi compliqués que dans les animaux vertébrés.

III.—ANIMALIA ARTICULATA.

Leur système nerveux consiste en deux longs cordons régnans le long du ventre, renflés d'espace en espace en nœuds ou ganglions. Le premier de ces nœuds, placé au dessus de l'œsophage, et nommé cerveau, n'est guère plus grand que ceux qui sont le *long* du ventre, avec lesquels il communique par des filets qui em*brassent l'œsophage* comme un collier. L'enveloppe de leur tronc

est divisée par des plis transverses en un certain nombre d'anneaux, donc les tégumens sont tantôt durs, tantôt mous, mais où les muscles sont toujours attachés à l'intérieur. Le tronc porte souvent à ses côtés des membres articulés; mais souvent aussi il en est dépourvu.

C'est parmi eux que s'observe le passage de la circulation dans des vaisseaux fermés, a la nutrition par imbibition, et le passage correspondant de la respiration dans des organes circonscrits, à celle qui se fait par des trachées ou vaisseaux aériens répandus dans tout le corps. Les organes du goût et de la vue sont le plus distincts chez eux: une seule famille en montre pour l'ouïe. Leurs mâchoires, quand ils en ont, sont toujours latérales.

IV.—ANIMALIA RADIATA VEL ZOOPHYTA.

Dans tous les précédens, les organes du mouvement et des sens étaient disposés symétriquement aux deux côtés d'un axe. Il y a une face postérieure et une antérieure dissemblables. Dans ceux-ci, ils le sont comme des rayons autour d'un centre, et cela est vrai, même lorsqu'il n'y en a que deux séries, car alors les deux faces sont semblables. Ils approchent l'homogénéité des plantes; on ne leur voit ni système nerveux bien distinct, ni organes de sens particuliers: à peine aperçoit-on dans quelques-uns des vestiges de circulation; leurs organes respiratoires sont presque toujours à la surface de leur corps; le plus grand nombre n'a qu'un sac sans issue, pour tout intestin, et les dernières familles ne présentent qu'une sorte de pulpe homogène, mobile et sensible.—*Le Regne Animal—Les Mammiferes*, p. 55: Paris (*s. a.*).

LECTURE VI.

EOZOIC AND PALÆOZOIC ROCKS—LINNÆUS' CLASSIFICATION OF ROCKS—WERNER'S CLASSIFICATION—EOZOIC ROCKS—GRANITIC ROCKS—PALÆOZOIC ROCKS—MALACOZOIC EPOCH—CHARACTERISTIC FOSSILS—ARCTIC GEOLOGY—MIGRATION OF LIFE.

WE have now to consider, from a general point of view, the Eozoic and Palæozoic rocks, reserving the Neozoic for subsequent discussion. You will remember that we divided all the rocks into four great groups, which we had some reason for believing to be nearly equivalents in point of time—namely, the Eozoic, the lower and upper Palæozoic, and the Neozoic rocks. In round numbers, if you consider that there is evidence of twenty British miles thick of strata having been deposited, taking the maximum thickness of each group of strata where we find it most developed, you may imagine the whole mass divided into four periods, corresponding each to five miles of thickness of rock; the first of these periods will be the Eozoic; the second and third, constituting ten miles of thickness, the Palæozoic; and the fourth, or uppermost, consisting also of about five miles of thickness, will be the Neozoic rocks. The miles of strata of the annexed Table are philosophical or geographical miles, that is, consisting of a thousand fathoms, and being somewhat longer than British miles. The Eozoic and Palæozoic rocks, therefore, occupy three fourths of the whole interval of time which has

elapsed since the period when strata began to be deposited on the surface of the globe. And yet we have found that the organic life of the Neozoic period, occupying one third of the period during which life abounded, and only one fourth of the whole lapse of time of which we have evidence, far exceeded in variety and developement of organic life the longer portion of time which we call the Palæozoic period.

TOTAL THICKNESS OF STRATA.

		Feet.	Geog. Miles.
Eozoic		26000	4.333
Lower Palæozoic	Lower Silurian	25000	5.082
	Upper Silurian	5500	
Upper Palæozoic	Devonian	9150	4.458
	Carboniferous	14600	
	Permian	3000	
Neozoic	Triassic	2200	4.512
	Jurassic	4590	
	Cretaceous	11283	
	Nummulitic	3000	
	Tertiary	6000	
			18,385

		Feet.
Eozoic	Quartz Rock	26000
	Roofing Slate	
	Primary Limestone	

The first person who appears to have conceived in any precise manner the essential problem of geology, namely, the fixing of a date to each group of rocks, was the celebrated Linnæus. He divided his *Systema Naturæ* into three parts—the mineral, the vegetable, and the animal kingdoms; and in

his *Regnum Lapideum*, published in 1770, part of the *Systema Naturæ*, he divides the rocks of the world, which, of course, include the rocks of Sweden, into five parts, calling these by the following names :—*Infimum*, *Secundum*, *Tertium*, *Quartum*, and *Supremum*. These are what he believed to be the strata of the whole globe, counted from below upwards. The first of these parts he made to consist of whetstone (*cote*); the second, of schists and slates (*schisto*); the third, of limestone (*marmore*), containing quantities of shells which were unknown to him, and which he calls foreign and marine shells;—"marmore, nidulantibus petrifactis pelagicis, sæpe etiamnum peregrinis." The fourth is also made of schist and slate (*schisto*); and the fifth, or uppermost, he forms of eruptive diorite or trap rock—"saxo rupestri, sæpe vastissimo."

The mountain rock, or *saxum rupestre*, of Linnæus, is a very old name for trap rocks. It is still used in many parts of Ireland, where the trap rocks are called mountain granite. It is common in the south of Ireland to find rocks which are crystalline syenite, called by the quarrymen mountain granite. They know it is not granite, and therefore distinguish it by another name. It appears to be a modification of the old term *saxum rupestre*, which Linnæus always used to designate trap rock.

Notwithstanding that the science of geology has been almost created since Linnæus wrote, and notwithstanding the great advances that have been made in it, yet in the last edition of Murchison's "Siluria" there is a description of the rocks of Sweden which might almost be supposed to be copied from Linnæus, though in reality deduced from his own observation. He calls the uppermost beds, erup-

tive greenstone; the next, black graptolite schists; the third, orthoceratite limestone, the lowest but one (the schist of Linnæus) he calls alum slate; and the lowest he calls fucoid sandstone, which Linnæus called whetstone. It is therefore evident that Linnæus observed the rocks of his native country with the eye of a most acute and accurate observer; that he saw the important groups into which they could be distinguished; and had also the sagacity further to perceive that these groups were deposited from water, and that they lay upon each other in the order of their age, and that therefore the uppermost, as he observes, must be the newest, and the lowermost the oldest.

I here place the classification of Linnæus* and of Murchison side by side:—

LINNÆUS.	MURCHISON.
1. Infimum, Cote,	= Fucoid Sandstone.
2. Secundum, Schisto,	= Alum Slates.
3. Tertium, Marmore, nidulantibus petrificatis pelagicis, sæpe etiamnum peregrinis,	= Orthoceras Limestone.
4. Quartum, Schisto,	= Black Graptolite Schists.
5. Supremum, Saxo rupestri, sæpe vastissimo,	= Eruptive Greenstone.

The doctrine of superposition is the foundation of geology; and the only addition that has been made to it by modern geologists is the exceedingly important one of characteristic fossils, which calls in to our aid, not merely the physical superposition of the rocks, but the contemporaneity of the same forms of life. This enables us to carry our geological surveys from one country to another, because, where we cannot avail ourselves of

* *Vide* Appendix (A).

the physical evidences of superposition, yet we may use the evidences afforded by fossils.

Before passing from this subject, I would add a word of caution as to the use of characteristic fossils. Every day's experience of geology convinces us that the doctrine of characteristic fossils, if it is to be relied on as a solid basis in geology, must be used with more and more caution. It must never be forgotten that, if we have the physical evidence of superposition, it is more certain and valuable than any evidence from fossils can be. It is now known that we may find fossils that have been considered upper Silurian in one country, occurring in other countries in the lower Silurian rocks, and *vice versâ;* and the same rule applies to other formations. Therefore, until the doctrine of characteristic fossils shall have been better defined than it is at present, we cannot use it as a proof of equal certainty with that derived from physical evidences.

Werner is the next writer demanding our attention. He appears to have borrowed his idea of classifying the rocks in the order of their occurrence from reading the work of Linnæus, but to have carried out the idea further, supposing that every particular description of rock was deposited at a particular age and time of the world. Werner's classification* has exercised so important an influence upon modern geology, that it is absolutely necessary you should be acquainted with it. Without going into detail, the following may be taken as a summary of his system:—

* My knowledge of Werner's classification is derived from Meuder's Introduction to the German translation of Jameson's "Mineralogy of the Scottish Isles:" Leipzig, 1802.

CLASS I. PRIMITIVE ROCKS—URGEBIRGE.

1. Granite—Granit.
2. Gneiss—Gneus.
3. Micaceous Schist—Glimmerschiefer.
4. Argillaceous Schist—Thonschiefer.
5. Porphyry—Porphyr.
6. Primitive Trap—Urtrapp.
7. Primitive Limestone—Urkalkstein.
8. Serpentine—Serpentin.
9. Quartz Rock—Quarzfels.
10. Topaz Rock—Topazfels.
11. Primitive flinty Slate—Kieselschiefer.
12. Primitive Gypsum—Urgyps.

CLASS II. TRANSITION ROCKS—UEBERGANGSGEBIRGE.

1. Greywacke—Grauwackengebirge.
2. Transition Limestone—Uebergangskalkstein.
3. Transition Trap—Uebergangstrapp.
4. Transition flinty Slate—Kieselschiefer.

CLASS III. FLŒTZ ROCKS—FLOETZGEBIRGE.

1. Old Red Sandstone (1st)—Rothe Sandsteinformation.
2. Flœtz Limestone (1st)—Alte Floetz Kalkstein.
3. First Coal formation—Steinkohlengebirge.
4. Flœtz Gypsum (1st)—Alte Floetzgypsformation.
5. Variegated Sandstone (2nd)—Bunter Sandstein.
6. Flœtz Gypsum (2nd)—Neuere Floetzgypsformation.
7. Flœtz Limestone (2nd)—Muschelkalk.
8. Flœtz Sandstone (3rd) = Quadersandstein.
9. Flœtz Limestone (3rd) = Kreidegebirge.
10. Flœtz Trap—Floetztrappformation,
11. Second Coal formation—Steinkohlenfloetze.

CLASS IV. DILUVIAL ROCKS—AUFGESCHWEMMTE GEBIRGE.

CLASS V. VOLCANIC ROCKS—VULKANISCHE GEBIRGE.

Werner thus divides all ordinary rocks into the Primitive, the Transition, and the Flat-lying rocks. The Primitive rocks, according to him, are twelve in number; of which I have given the names. The Transition are four in number; and the Flat-lying rocks are eleven. He believed that this series of

rocks was developed in a graduated order from the beginning of the stratification of the globe to the close of it, and that they were all deposited from water.

Mr. Hutton had the merit of calling attention to the facts that are to be observed in the geology of Scotland, which lead us to believe that this opinion of Werner was erroneous, and that many of the rocks considered by him to have been formed from water were really formed by the action of fire. Such are granites, trap rocks, greenstones, basalts, and so on. This doctrine of Hutton has been carried by particular geologists to an extreme, which was to be expected, since it is, in fact, a reaction from Werner's doctrine. The German and French geologists never altogether assented, to the extent to which English geologists did, to the arguments advanced by Hutton; and there now appears to be a strong tendency amongst geologists to adopt an intermediate course, and to admit that granite is partly of aqueous and partly of igneous origin, and not to contend for the extreme views either of Werner or of Hutton. All geologists have abandoned the doctrine of Werner that the rocks of the earth were deposited in a regular lithological order; and we know now that we must seek in such evidence as that of characteristic fossils for proofs of cotemporaneity in the rocks of the different parts of the world, and that sandstone in one country may correspond with limestone in another, and with slate in a third.

With regard to the eozoic rocks, which constitute five miles in thickness of the crust of the globe, it was at one time believed that wherever metamorphic rocks occurred, they were all necessarily of the same

age. Geologists have been led to modify considerably this view, though few have adopted to their full extent the doctrine of Lyell, who maintains that metamorphic rocks may be found in any age of the world—that they may be tertiary, oolitic, and so on. There is on the whole a preponderance of evidence to show that the greater proportion of the eozoic and metamorphic rocks were deposited in the very oldest periods of the world's history, and it is only that class of eozoic rocks that are supposed to be included in the 4⅓ geographical miles in the Table of pp. 91, 125; for if metamorphic rocks occur anywhere else in the series, their thickness has been measured as part of the formation to which they belong. There is no good evidence of very modern rocks having become metamorphic; and the great bulk of those with which we are acquainted are genuine old rocks, lying below the lowest Silurians.

The principal mass of eozoic rocks in Europe lies along the chain of the Scandinavian mountains, passing across the sea to Scotland and Ireland, where in the north-west, in the county of Donegal, we have a continuation of the granitoid rocks of Scotland, these again being a continuation of the granitoid axis of Norway. Along this great axis we have reason to believe that the strata we have to deal with are the oldest, or amongst the oldest, that are to be found in Europe. They are genuine eozoic rocks; they lie below the lowest Cambrians and the lowest Silurians. They are composed of a granite centre, which appears everywhere to have a gneissose character, and to present the appearance of having been produced cotemporaneously with the upturning of the strata. In many parts of these countries it is impossible to tell where the

granite ends and where the gneiss begins, as both possess the same stratified appearance; and in parts of Donegal this interstratification is carried so far, that bands of limestone are occasionally stratified vertically with pure granite on each side, as if the limestone and the granite had been formed side by side. It is impossible to reconcile such a fact as this with the purely igneous or lava theory of the origin of granite; and therefore I think we must abandon the igneous as an exclusive theory of the origin of granite.

Another great mass of crystalline or eozoic granitoid rocks runs east and west across Europe; but this is certainly more modern in its origin than the Scandinavian chain. The granite of the Pyrenees, the Alps, and the Caucasus, occurs in a narrow band flanked on either side by highly inclined metamorphic slates and limestone. In many parts of the three districts it does not occupy more than a few hundred yards across; and it is immediately succeeded on either side by highly inclined gneissose beds, to which the name granite has been very properly denied. The age of these inclined beds which flank the granite in these countries, and perhaps also in the Himalayan mountains in Asia, which form part of the same range, has been a subject of much dispute. But I believe it will not now be denied that, although many modern rocks, such as nummulitic limestones and others, have been upraised along the line of this great east and west fracture of the globe, there are to be found also metamorphic rocks of extreme antiquity lying on the flanks of the narrow granite band that originally formed these ranges of mountains. Thus we have in Scandinavia evidence of the eozoic rocks being contem-

poraneous with the granite which forms the mountain chains, and also in the peninsula of Singapore we have abundant evidence of the existence of exceedingly ancient eozoic rocks which cannot properly be ranked with modern metamorphic rocks at all. The granite axis of Ceylon runs nearly north and south, and appears to be a continuation of that which composes the range of South India. Throughout the whole of these Eastern lands granite is rare as compared with gneiss; and I have recently been informed by a skilful observer, who spent some years at Singapore, that it is impossible, although you see nothing but granite at Singapore and in the mountains about it, to get even a hand specimen which does not present the gneissose and stratified character. On the flanks of the Cingalese granite a series of gneiss, slate, and limestone beds occur, and in those beds are the valuable and rare minerals that have made Ceylon and the granitic regions of the East so famous. But they all appear to belong to the oldest periods of the earth's history—to that great group of rocks which were formerly called "azoic," because geologists could not find traces of organic life in them, although it is now generally believed that some life did exist on the globe at the time when they were deposited. In North and South America we find again repeated the same phenomena which we observe in the Himalayan mountains in Asia, and in the Pyrenees and the Alps in Europe, namely, a chain of mountains forming the axis of the continent, in which granite is comparatively rare, occupying only a narrow linear band along the centre of the axis, flanked on either side by metamorphic slates, and these again succeeded by rocks of later ages in the world's history.

It has been inferred, because nummulitic and other modern limestones were found in the Pyrenees, the Alps, and the Himalayas, that therefore these eastern and western chains were of very recent elevation. In like manner, parts of the Andes have been supposed to be of recent formation, from the fact of modern oolite rocks being found developed on them in great abundance. But we must not forget that, if these great mountain chains represent, as we believe them to do,* fissures and cracks originally formed in the cooling crust of the globe, they may have been elevated many times and depressed many times in the course of the earth's history; and that, from the time the first granitic eruption poured through the fissure to the time when the nummulite limestone was formed, the chain may have been raised and submerged many times. It is therefore no argument against the age of a range of mountains to say that modern rocks are found very high upon its flanks. That is only a proof that the range has been recently under water. But we have every reason to believe that the physical features of the globe sketched out in its high mountain chains and deep sea valleys have been always permanent, that they are the necessary result of the laws of the cooling of the globe, and that they have been raised above the surface of the sea and depressed below it many times during the history of the earth.

We now come to the Palæozoic period, divided into two parts, viz., Lower and Upper. This division is made only for convenience; the truth is, the whole Palæozoic period is well defined and well

* *Vide* Appendix (B).

characterized, and differs widely and strikingly in its zoological characters, and in some of its mineral and fossil characters, from the Neozoic period which follows it.

The lower Palæozoic period includes the Cambrian and Silurian rocks, or systems, as it is the fashion to call them. The upper Palæozoic includes the Devonian, the Carboniferous, and the Permian. These names must be regarded as temporary only. It is not to be supposed that an obscure English county, where the strata are themselves very perplexing, can give a name to a great period of the earth's history. It is probable that, when the geology of the whole globe shall be studied, the names of Cambrian, Silurian, Devonian, Carboniferous, and Permian will disappear, and some more rational system of nomenclature be agreed upon among geologists of all nations. At present the names of the different strata constitute a perfect scientific Babel; and French, German, English, and American names have been given to all, so that the study of synonymes has become as necessary and as painful in geology as it is in zoology or botany. The American geologists, in particular, have distinguished themselves by their rebellion against the English names; and some enthusiasts among them have called certain strata the auroral, the midday, the vesper strata, and so on, referring to the age of the world at which they were formed, so that we may look forward in due course of time to hear American geologists speak of the midnight beds, the one o'clock A.M. outliers, the two o'clock P.M. deposits, or even the 20 minutes past four sandstones.

The term "Palæozoic" is certain to remain as

the name of a great epoch, because that period is separated so widely from the Neozoic which follows it by the character of its fossils and by the physical conditions under which they were deposited, that this name runs no risk whatever of being disturbed.

The general character of the life which prevailed during the Palæozoic period may be inferred from a study of Diagram No. II., in which, as I have already explained in Lecture V., the horizontal line denotes time. Each of the four intervals is equivalent to about 4½ geographical miles of thickness of rocks, and the vertical lines represent the percentage of coexisting species. On examining the line of Crustaceans in this diagram we find a remarkable law. The Crustaceans, from the time of their first appearance on the globe, acquired rapidly more and more zoological importance till they attained the position of 24 per cent. of the whole creation. So far as we know from the fossils—which of course are our only means of knowledge—at that period, of every four creatures living on the surface of the globe one was a Crustacean. That remarkable phenomenon occurred during the lower Palæozoic period; and we must, therefore, consider that period as pre-eminently the Age of Crustaceans. Accordingly Mr. Dana has proposed that, instead of calling these periods of the earth's history by local names, we should give them names derived from their organic remains, which is possibly the principle of nomenclature that will ultimately prevail. He proposes to call the lower Palæozoic the Age of the Mollusks.* The Crus-

* I have suggested the term *Malacozoic* for this epoch; as it includes both the Malacoderms and Malacostraca, or Mollusks and *Crustacea*, of Aristotle.

taceans, having reached their maximum of importance, fell off in the upper Palæozoic period to less than five per cent.; continued at that low rate of importance throughout the greater part of the period, again rallied towards its close, and at the commencement of the Neozoic period attained again an importance equal to 10 per cent. of the creation. Afterwards they fell off again, and have never succeeded in attaining anything like the zoological importance that they had before, during the lower Palæozoic epoch. Therefore the term *Malacozoic* would be well suited to represent this important fact, because it shows that there was a period when these Crustaceans attained their maximum, not only comparing them amongst themselves, but also their maximum of importance as inhabitants of the globe compared with other animals.

If we now examine the curve of zoological importance of the Fishes, we find that it runs suddenly up to its highest point in the early part of the upper Palæozoic period, when Fishes attained to something like 23 per cent. of the then coexisting species. They fell off afterwards, like the Crustaceans; rallied again at the commencement of the Neozoic period, and have since fallen off again. This important fact may be commemorated by giving to the Upper Palæozoic period the name of *Ichthyozoic*.

The great zoological fact, then, which characterizes the Palæozoic period is, that it may be divided into two epochs, during one of which Crustaceans attained the highest developement of all creatures on the surface of the globe, and during the other of which Fishes reached their maximum. We may add to the Fishes another group of organisms—

mean the fossil plants. During the second part of the Palæozoic period Fishes and Plants attained their maximum of developement. Reptiles and the Mammals made their appearance subsequently. Starting from these facts, Professor Dana proposed to divide the world into five ages, which might be called the age of Mollusks, the age of Fishes, the age of Reptiles, the age of Mammals, and the age of Man.

For these terms I would substitute the following equivalents:—The Malacozoic, Ichthyozoic, Saurozoic, Mastozoïc, and Anthropozoic Epochs.

One very important question remains to be noticed. We frequently speak of the strata which are observed to be deposited in every part of the globe; but until the theory of characteristic fossils was invented, it was impossible for us to identify the rocks of one country with those of another. At the time that William Smith invented this theory, it was regarded, like Werner's old theory of the successive deposition of strata, to be an infallible guide to the age of rocks. Mr. Smith made the discovery while constructing some canals, in the course of which he was obliged to cut through the beds of oolite and lias which exist in the central parts of England. These beds are distinguishable from each other by very precise and very definite characteristic fossils; and therefore he generalized—as most men will do, when they get hold of a good idea—from too small a basis of facts, and extended his theory of characteristic fossils to apply to every country. I have already told you that it has received several severe shocks in its application. In the first place, we have been forced to fall back on the theory of *representative species,* instead of characteristic species. We see

that the fossils of the coalfields of the carboniferous limestone of Europe are not the same as the fossils of the coalfields of America or of Australia, although they are unquestionably like them; and we are now in the habit of saying that they are represented by analogous and cognate species in those other deposits. This, however, would be no impediment to the practical geologist, because the resemblance between these representative species is so close, that for all useful purposes he would regard them as identical. But the theory of characteristic fossils is threatened with another danger, for it appears to be exceedingly doubtful whether fossils of the same kind were necessarily deposited at the same time in all parts of the world. It has been already established, that sometimes fossils of a particular description have lived on in certain localities, as in some of the Silurian strata of Bohemia, far beyond the period when they became extinct in other places. Now, this is quite confirmed by what we know of the present distribution of marine animals; that favourable conditions may occur in a particular part of some sea which will allow of animals living on in it long after the majority of that group of animals has been destroyed in all the surrounding seas. But if we believe that in the older periods of the earth's history the heat of the globe performed any part in influencing climate, we must then be prepared to believe that there was a migration of life from the poles continually towards the equator, and that, therefore, in supposing fossils to represent an epoch, we must take account of the latitude in which they are found, as well as of the characteristic species. If this doctrine were admitted, it would sadly com-

plicate our determination of contemporaneous periods in different parts of the world; and yet it appears almost impossible to resist the evidence that can be brought forward in favour of it. I place before you a map of the Arctic regions, coloured geologically, in order to illustrate this statement. We have discovered in the most extreme northern regions that our sailors have reached, representatives of a much greater variety of geological periods than was supposed likely to be met with. A large proportion of the map is covered by granitoid rocks, which are of extreme antiquity, flanked, as in other parts of the world, by their characteristic eozoic rocks. This was the description of rocks which it was commonly supposed would be met with in high latitudes. The opinion has been frequently expressed by geologists, that the shape of the earth, bulged out at the equator, might be due simply to the action of waves and water upon its surface; a view which, though incorrect, as can easily be shown, yet contains so much truth in it, that we might use it as an argument that we should expect *à priori* that the thickest masses of strata should be deposited at the equator, and the thinnest at the poles. The globe having consolidated from its molten condition, and the water having condensed from the atmosphere, when it became sufficiently cooled for the formation of the sea surrounding the globe, then commenced in the crystalline rocks of the primitive globe the first process of mechanical denudation; and that mechanical denudation must have unquestionably tended continually to draw the materials composing the globe, as they were washed off from its surface, towards the equator and from the poles.

This action was, of course, disturbed—assisted in some cases, and counteracted in others—by the reaction of the interior of the globe upon its crust, causing protuberances of mountain chains, sometimes helping and sometimes impeding the mechanical action of the water. Arguing thus, we should expect to find the old granitic rocks more developed in the high latitudes, and the eozoic rocks more developed as we went further south and further north in either hemisphere. This, however, is not the case. It is not the granite axis alone of North America that runs up to these high latitudes, but the upper Silurian rocks, containing quantities of limestone and a great abundance of fossils, accompany the granite; and in Banks' Land and Melville and Cornwallis Islands we have, lying on these Silurian rocks, at small angles of dip, characteristic carboniferous rocks, and even coal-beds; and lying upon these, again, in several places, as, for example, at Exmouth Island, and Prince Patrick's Island, we have two remarkable spots in the northern Arctic regions, in which characteristic fossils of the lias rocks, which were deposited in the Neozoic period, have been discovered. Now, we have always been accustomed to argue as to the climate of these periods from their fossils; and, whatever be the value of our arguments, although they are not thought as conclusive now as they used to be, yet, making many deductions for their uncertainty, there undoubtedly is a balance remaining in favour of the higher temperature of the older periods of the earth's history. Now, if a temperature much hotter than that which now prevails in England, which is supposed to have been necessary for the ammonites

and the great sea lizards of the Saurozoic epoch be supposed to have existed at Melville Island it is impossible not to believe that a temperature would have then existed at the equator that would coagulate albumen, and in which, of course, no animal could live.

It is therefore perfectly certain that, if we allow the heat of the globe to have at any time so influenced the climate of those high latitudes as to have made them habitable, we must admit that at the corresponding period the equatorial portions of the globe were not habitable to the same class of creatures. Therefore, if this be true, there must have been a perpetual migration from the polar towards the equatorial regions. The animals that required a certain temperature must have migrated further and further towards the equator as the earth cooled, and as the conditions became more and more unfavourable for them in the high latitudes; and they must have been succeeded in those latitudes, gradually, by other animals such as we now see there, which were intended by their Creator to inhabit those high latitudes perpetually, and which were therefore under no necessity of seeking a warmer climate. This would introduce very serious complications into our idea of characteristic fossils, because it would require you to say that fossils of a given kind, found in India, for example, although they presented very closely analogous forms, and perhaps might be even identical with fossils found in England, yet if they arrived in India by a gradual process of emigration caused by the lowering of the temperature, would not be strictly contemporaneous with those in England. And it is quite possible, *I think*, that, when our knowledge of the

geology, and particularly of the fossil contents of the strata, of the whole globe, shall be greatly improved, considerations such as this must come into play; and that we are now calling large groups of rocks and masses of formations contemporaneous which we shall be ultimately obliged to admit are subdivisible into many periods of time, and that, strictly speaking, the term "contemporaneous" does not apply to them. We must never forget, that in studying geology we are not studying history. It is like the study of archæology, and not of history; and therefore a certain amount of license and poetry must be allowed to the speculator in it, that would be forbidden to the accurate historian. In archæology, writers divide their time into the stone period, the bronze period, the iron, and the gold periods, which resemble our subdivisions in geology. The progress, however, of the science in making us more acquainted with the deposits of other countries must ultimately correct those theories; and I have no doubt that, when this correction is applied by a more extended knowledge of the strata, although much of what is merely local in our classifications will disappear, a very considerable portion of them will remain, and will be permanently adopted.

APPENDIX (A).

LINNÆUS' THEORY OF THE FORMATION OF ROCKS.

The following is Linnæus' classification of rock formations, and his theory as to their production:—

Strata Telluris ex ruptis montibus conformia sæpius vidi, nec tamen dixero omnia ejusdem generis esse et pelagica.

I. Infimum e *Cote*.
II. Secundum e *Schisto*.
III. Tertium e *Marmore*, nidulantibus petrificatis pelagicis sæpe etiamnum peregrinis.
IV. Quartum e *Schisto*.
V. Supremum e *Saxo* rupestri, sæpe vastissimo.

Oceanum matrem telluris esse nullus non videre potuit.

A. *Imbribus* nitrosis turbatur, præcipitatur et crystallisatur aqua maris in Arenam, maris fundum obtegentem.

B. *Fuco natante* pelagus passim latissimeque obducitur, unde *quies* aquæ non obsecundantis variabili vento.

C. *Humus* emortui Fuci (B) sensim descendit, Arenâ (A) levior, dum pergit Fucus (B) in pratum natans concrescere.

D. *Vermes* pelagici, Mollusca, Testacea, Litho- et Zoophyta, Piscesque natantibus ovis, Avesque compeditæ impennesque sub Prato fucoso pelagico (C) pascuntur.

E. Pacatâ sub aquâ (B) depluit sedimentum Argillaceum, cum sensim emortuorum vermium testis (D) calcareis usque in cumulum altum superficiei maris proximum, dum pressio excitans aquam (B) depellat pelagica (D).

F. Ad Scopulum formatum, ex suâ lege, rejicit mare inprimis fucos copiosos varios, in *humum* deliquescentes usque dum nuda terra inferior *arenacea* emineat, quæ siccata volitat, mixtaque in sabulum saxaque concrescit.

G. Seculorum dein longiori avo, temporumque perenni quiete;

I. Concreta *Arenâ* (A) in *Cotem* (I.) varie sed proprie fissam.

II. Ferruminata *Humo* (C) in *Schistum* (II.) lamellosum combustibilem.

III. Indurata *Argillâ* (E) in *Marmor* (III.) e vermibus coagulatum.
IV. Ferruminata *Humo* (F) in *Schistum* (IV.) superiorem, modo priore.
V. Concreta *Arenâ* (F) in *Sabulum* (V.) immixtis peregrinis.

VI. Hoc dein in lapillos, et hi in saxa, hæc in rupes, subsidente demum lente maris aquâ evasit *Mons*, nec potuisse altissimæ Rupes (V.) natasse supra Argillam, dum, antequam calcificaretur, vermes pelagici in eâ adolescerent, ideoque et Rupes saxeas altissimas ævi veros filios esse, dum omnia obmutuere, ipsi loquantur lapides; *tandem ævi longinqua valet mutare vetustas.*

APPENDIX (B).

FORMATION OF MOUNTAIN CHAINS.

THE astronomical changes of the globe, resulting from its secular cooling, determined the form and conditions of its seas and lands, long before it was fit for the habitation of any living creature; and I believe that the traces of this original crumpling of the earth's surface are still to be found in the distribution of its mountain chains and sea valleys. As the earth's surface cooled, it contracted upon the liquid interior, by the reaction of which, being incompressible, it was ultimately rent into certain fissures, elevated above the general surface, through which flowed the molten glass that afterwards, when metamorphosed by the action of water, became granite, and subsequently the trappean lavas. These fissures of elevation had a meridional direction, from north to south; and between them lay, as a matter of necessity, deep valleys of depression, into which the aqueous atmosphere of the globe was distilled on cooling. The existence of those meridional lines of fissure or elevation and depression is mathematically demonstrable from the conditions of cooling of a body shaped as the earth is; and these meridional lines of fissures were afterwards succeeded by transverse lines of elevation and depression in each hemisphere, following the line of small circles of latitude. Let us examine briefly, from this point of view, the structure of the present surface of the globe. Two irregularly-shaped valleys, but on the whole following a meridional course, traverse the surface of the earth from pole to pole. One of these, the Atlantic valley, passes close along the east coast of Greenland, between that country and Iceland, and thence extends southward on the meridian of 20° W. to the South pole itself. This valley is divided in the North Atlantic by the "middle ground," containing the Azores, into two valleys, of which the western, though less straight, is somewhat the deeper of the two; while in the South Atlantic its course is more directly southern, and, from the little we know of it, both by soundings and tidal observations, it appears to be considerably deeper than in the North Atlantic. The

second meridional valley, starting from the south, keeps along the west coast of South America, in the meridian of 90° West, in a direction due south and north, in very deep water, so far as we can infer from the progress of the tidal wave. Having reached the equator, it is directed to the west of north along the coast of North America, and enters the polar basin through Behring's Straits, in the meridian of 170° W. These two great meridional valleys divide the globe into two lunes, one containing the continents of the Americas and Greenland, and the other containing the Great Continent, Africa, Australia, and the large islands north of it.

These two portions of the earth's surface appear to me to have had their equilibrium destroyed by meridional fractures in a manner precisely similar, but inverted with regard to the northern and southern hemispheres in the two cases. Each lune of the globe may be regarded as an arch, having for buttresses the meridional lines of depression already noticed. These buttresses having given way, the whole earth has broken, but in a different manner in the northern and southern halves. An arch, or dome, may give way when its buttresses fail, either by the bursting up of the crown and falling in of the hips, or by the falling in of the crown and bursting up of the hips of the arch. Both these cases have occurred, as I conceive, in each of the two great divisions into which the meridional valleys divide the globe.

1. The Great Continent.—In the northern hemisphere this mass is bisected by the meridional chain (60° to 75° E.), extending from 7° N. to 77° N., containing the western Ghauts, the Bolor and Solimaun Ranges, the Ural Mountains, and Nova Zembla, through a distance of 4200 geographical miles. This ridge of elevation I suppose to represent the bursting up of the crown of the arch. In the southern hemisphere, however, the other form of fracture has occurred. The crown of the arch has fallen in, as shown by the deep valley of the Indian Ocean lying between Africa and Australia,—a valley the depth of which, as indicated by the progress of the tidal wave, is comparable with that of the South Atlantic. On either side of this central valley the hips of the arch have burst up in the meridians of the Cape of Good Hope and Van Dieman's Land, forming the meridian chains of mountains of Africa and Australia. These meridional chains are nearly symmetrically situated with respect to the crown of the northern arch or meridian of Cape Comorin, that of the Cape of Good Hope lying 60° W., and that of the eastern meridional chain of Australia 65° to the east of the meridian. In the northern hemisphere a secondary fracture has taken place, which I shall presently consider, and which modifies the primary or meridional fracture.

2. The American Continents.—In America the southern arch of the lune has burst up its crown along the meridian of Cape Horn, forming the great chain of the Andes, which extends north and south for 3900 geographical miles, and is in every respect the counterpart of the Ural and Solimaun chain of Asia. In the northern hemisphere, however, the other mode of fracture has taken place, the crown of the arch having fallen in, forming the depression occupied by Baffin's Bay, Hudson's Bay, and the central lowlands of North America; while the haunches of the arch have burst up along the line of the Rocky Mountains and the chain of Greenland and the Alleghany Mountains. We have thus the two great masses of land on the globe constructed by the original fracture on the same plan, but reversed with regard to hemispheres, of the lunes of the globe in which they are placed.

The primary meridional fractures having occurred, the secondary fractures are to be explained on the principles of the equilibrium of a dome, and not of an arch. I regard the whole northern hemisphere as one dome, and the southern as another. In the northern hemisphere the centre of the dome has fallen in, forming a depression at the pole, or Arctic Basin, and the hips of the dome have burst up along the small circles of latitude lying between 35° and 46°. In the great continent this up-burst of the dome may be traced from the Pyrenees, through the Alps, Balkan, Anti-Taurus, Caucasus, El Burz, Hindoo Koosh, the Thian Shan, and Shan Garjan Mountains, to the city of Pekin, through a range of 150° of long., or 6700 miles in length. This astonishing range of mountains continues with but little deviation along the parallel of 40° N., forming a striking contrast to the meridional chains which traverse great circles of the globe. It is also a very remarkable fact that the Snowy Mountains of North America (700 miles in length), which form the only east and west range in that continent, are found to run along the parallel of 41° N., which we have every reason to believe resulted from the simple mechanical principles influencing the fracture of the northern dome; and even in the bed of the Atlantic a shallow band (the proposed line of the French telegraph) crosses the ocean in the same parallel from the Newfoundland bank to the Pyrenees. In the Southern Hemisphere, on the contrary, the equilibrium of the dome has given way by the reversed process—the crown having burst up, forming the Antarctic Continent, and, the hips of the dome having sunk in, form the small circle of deep water 40° S., which is interrupted only twice; by New Zealand, and the southern prolongation of the Andes.

I do not mean to assert that the present valleys and lines of elevation were those of depression and elevation of the primeval *crystal glass of* the fractured crust of the original globe; but I do

believe that the lines I have pointed out were originally, and have always been, lines of either elevation or depression, and have constituted alternately the axes of continents or the valleys of the ocean. In a flat-arched dome, like the crust of the earth, very slight modifications of external conditions would convert the lines of depression into lines of elevation, and *vice versâ*; and I think that sound geological reasons could be adduced in support of the views I have advanced, which are based simply on mechanical reasonings. Although we have good geological reasons for supposing that the present line of elevation in the parallel of 40° N. latitude took place during the period preceding the tertiary, yet there is abundant evidence to show that it took place along the line of an ancient fissure, through which was poured the granite glass, considered by M. Durocher as the outer solidified layer of our globe.

LECTURE VII.

MINERAL SYMMETRY — VEGETABLE SYMMETRY — ANIMAL SYMMETRY—FORAMINIFERA—IMPORTANCE OF SYMMETRY —CELLS OF BEE—OPINION OF PAPPUS—MARALDI AND REAUMUR—OPINION OF DARWIN—LAWS OF PRESSURE—BOTANICAL ILLUSTRATION.

In the present Lecture I shall make some remarks —introductory to the separate description of the various groups of fossils—on the geometrical laws that are found to influence the forms of plants, animals, and minerals; and, in the case of animals, on the geometrical laws to which some of their instincts are subject. The forms of animals, and the geometrical laws that regulate them, are of importance to the naturalist, and form a subject which has not been neglected, on which much has been said and written; and I therefore cannot hope to add much that is new respecting it, though, perhaps, I may succeed in putting a few old things in a somewhat new point of view. With regard to the geometrical tendencies of some of the instincts of animals, I hope to remove from this subject somewhat of the mystery with which it has been surrounded by writers on both sides; for, like every other important question, it has had two sides given to it.

Having sketched for you the geometrical laws that regulate the forms of animals, and the geometrical tendencies of some of their instincts, we shall then commence a brief description of the fossil

forms, in the course of which we shall find this investigation of the geometrical laws that regulate the forms of animals to be even more important to the geologist than it is to the naturalist. The reason of this is that the geologist depends so much for his knowledge of the former life that existed upon the globe upon the hard and durable parts of animals, their internal and external skeletons, where these geometrical arrangements and tendencies are most exhibited, that his attention is more called to these, and he derives more aid from the consideration of them than the naturalist, who has much more means of studying the animals in other and more important relations.

Of all the kingdoms of nature, the mineral kingdom is that which is most completely subjected to the tyranny of geometry. Here geometry and its laws exercise an absolute authority. The crystalline forms which minerals are capable of receiving —which are a necessary part of the definition of a mineral—are sometimes so complex, but yet subjected to such regular laws, that they tax the resources of the highest branches of geometry to expound them. Therefore it is that we must inscribe over the portals of the science of mineralogy what Pythagoras did over his school of philosophy, Οὐδεὶς *ἀγεωμέτρητος εἰσίτω*. It is perfectly impossible to understand the science of mineralogy, if we are to include the crystalline forms of minerals in that study, without being a good geometer; and the beauty of the laws which connect the planes of crystals together has, for a long period, attracted the attention not only of mineralogists, but of mathematicians. No one, therefore, will dispute, for a moment, that in this kingdom of nature geometry

and geometrical forms are absolutely tyrannical in their sway. Everything appears to be subjected to their influence. Even when you have a number of crystals or minerals together, each obeying its own laws of crystallization, we find that some crystals, as if endowed with a greater power of crystallizing than others, will force the weaker forms of crystals to accommodate themselves to their shapes; so that it is not an uncommon thing to see in a rock a mass of large crystals which are not homogeneous, but which contain, entangled in their interior, numbers of crystals often of totally different forms of minerals that have been compelled by the general crystallizing forces that surround them to take up positions different from what they would naturally have assumed, and to form part of the large crystalline mass.

The crystalline forces in minerals, which, whatever they are, probably are more dependent upon the escape of heat and of electricity from minerals than upon any other causes, act with reference to certain planes and lines; and by acting with reference to those planes and lines which occupy fixed directions and positions in space, the result is a crystalline form, the investigation of which is a subject that belongs to pure geometry.

In the vegetable and the animal kingdoms we have, of course, no such absolute subjection to the laws of geometry as in the case of minerals.

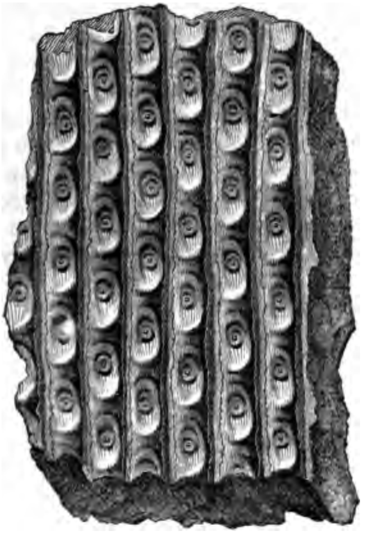
In the vegetable kingdom we find the tendency towards geometrical forms to be more perfect than in the animal kingdom; and here the symmetry of form with reference to geometrical laws may be summed up in saying that it is related to the line, to the cylinder, and to the helix. Let us imagine

a central line which is the axis of a right cylinder; and with any centres taken along the central axis, let us trace at intervals a number of circles, and we shall find a type to which many forms of vegetation, particularly the lower forms, are referrible. As the axis of the stem grows, the leaves are developed on these circles at regular intervals, which vary with the rate of growth, and the circles themselves are connected by geometrical laws as to the manner in which the leaves grow upon them. If a given number of leaves grow upon each circle, there will be the same number of leaves upon the circles above it and below it; and the position of these leaves will be regulated by the following geometrical law:—"Each leaf is placed, in the circle above and below, intermediate to the leaves of the middle circle." This is commonly called an arrangement of leaves in whorls. The common arrangement of opposite leaved plants is an example of it; and there is no exception, as far as I know, to the geometrical law, that in the whorled plants the leaves are placed in each successive whorl, in positions intermediate to those of the leaves of the whorls above and below.

In Fig. 1 is represented a portion of the stem of *Sigillaria oculata*, a well-known coal plant, whose arrangement of leaves is that just described. The stem is fluted longitudinally, and the leaves are arranged transversely in whorls, in such a manner that each leaf scar is intermediate to two leaf scars of the whorls above and below it. The *Sigillariæ* of the coal period are closely allied to the *Lycopodiaceæ*, or club mosses, and owed their superior size probably to the greater quantity of carbonic acid and to the greater heat of the atmosphere of

the time at which they lived. They occupy a low position in vegetable life, and are therefore more subject to geometrical laws than the higher torms of vegetation; but even in these we frequently find the law of whorled arrangement in alternate suc-

Fig. 1.



SIGILLARIA OCULATA.

cession rigorously enforced, as in the case of the *Ericaceæ* and *Casuarineæ*.

From this arrangement the passage is easy to the simple helix, in which the leaves, instead of being arranged in circles on the cylinder of growth, *are placed* upon a helix described upon the cylin-

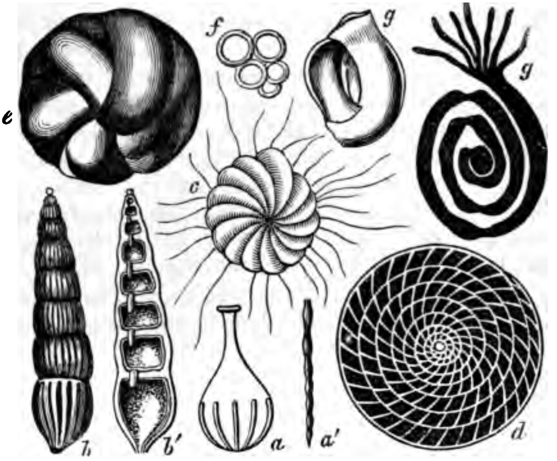
der. All these forms of symmetry are referrible to the line, to the cylinder, and to the helix. In the fructification of plants, where we have leaves in an arrested condition of growth, according to the opinion of botanical writers, the longitudinal growth becomes interrupted, and we find that the whorled arrangement universally takes the place of the spiral form of developement which prevails in the arrangement of the leaves of the stem.

In the animal kingdom we have many forms of geometrical symmetry analogous to this. Amongst the *Foraminifera* we have simple instances of rectilinear growth; as, for example, in the Rhizopod, which is called the *Nodosaria rugosa*, Fig. 2, *a'*. It grows in a simple line by a series of cells. Each cell is filled with a substance denominated "sarcode," which appears to be of homogeneous texture, not endowed with nervous power, with muscular fibres, with an alimentary canal, or any of the parts of more highly organized animals, but simply with the power of forming cell after cell in a particular direction from itself.

In the simplest of these forms of life the geometrical arrangement is rectilinear. In others of the same group, indeed in many others, it becomes referrible to a spiral line lying in a plane; and the symmetry with regard to a line that we first observed in straight rectilinear developement becomes the symmetry of a plane curved spiral in such an example as the *Nummulite*, Fig. 2, *d*. Occasionally also, in the Foraminifera, the curved spiral ceases to be plane, and is wrapped on a conical surface, forming what is called a trochoid spiral; an example of this is shown in the *Cassidulina*, Fig. 2, *e*.

In the accompanying Fig. 2 are represented some of the most common forms of Foraminifera, recent and fossil.

FIG. 2.



FORMS OF FORAMINIFERA, RECENT AND FOSSIL.

a, *Lagena striata*.
a′, *Nodosaria rugosa*.
b, *Marginulina raphanus*.
b′, Section of same.
c, *Polystomella crispa*.
d, *Nummulites lenticularis*.
e, *Cassidulina lævigata*.
g, *Miliolina seminulum*.
g′, Animal of same.
f, *Textularia globosa*.

Of these *a*, *a′*, *b*, *b′*, illustrate the rectilinear symmetry, and *c*, *d*, *e*, *g*, *g′*, illustrate the symmetry of the plane and trochoid spiral curve. In the first of these cases we must suppose the original Protozoon endowed with the faculty of growing by the perpetual addition of cell to cell, and also with the tendency of that continued growth, cell after cell, to form a right line.

In the second case, we must suppose the growth

of cell to cell to be directed in a spiral, lying in a plane or on a cone; and thus we have the symmetry of a plane spiral curve, which you may consider as still referrible to a right line, but the line has now become perpendicular to the plane in which the spiral curve is traced. It is, in fact, the same as if we supposed in the symmetry of the plant that a spiral helix was formed upon a conical surface, and not upon a cylinder, and that then the vertex of the cone was suddenly pushed down to its base. The spiral helix would then become a spiral situated in a plane, like that which is found to prevail in many of the lower forms of life. This form of life and this kind of geometrical symmetry are well known to the geologist. One of the most interesting and beautiful forms of the Protozoa, the nummulite, constitutes also one of the most important of our fossils. These nummulites are geologically of considerable importance; but I now speak of them merely with reference to the geometrical laws of their growth. They consist of a number of cells, which grow one from the other in a manner regularly spiral. This is still symmetry referred to a line, the helical symmetry reduced to a plane. If the conical surface which I have supposed, on which our helix is traced, had not its vertex brought down to its base so as to give us this spiral symmetry on a plane, it would form a trochoid. Here we have a cone with a helix described upon it, which is not like the helix described upon the cylindrical axis of a plant, but becomes a form which gradually increases as you approach the base, and which has got the name of trochoid. This is, as you know, a common form of the symmetry assumed by the Gasteropods.

The highest of all the forms of symmetry which animal forms are capable of taking appears to be in reference to a plane, and not in reference to a line; and it is in this respect that the animal kingdom takes up a position as far above that of the vegetable kingdom as that of the latter is superior to that of the mineral kingdom. It derives its symmetry from reference to a plane. All the higher animals have a bilateral symmetry, referrible to a plane.

The symmetry of all the shells of the Mollusca has reference to a plane; and that of the Cephalopoda has reference to a plane and a line perpendicular to it; many of them being developed according to this law of superior symmetry; and the whole animal is divided into right and left sides, which are symmetrical with regard to the plane of section. All the bivalves among the Mollusca are possessed of a bilateral symmetry; and, in fact, the Crustaceans, the Annulosa, and even the Echinoderms, which may be considered as having the symmetry of the plane rather than of the axis, possess this higher form of symmetry. In some of the corals, the symmetry is of a simpler and more vegetable form, and has relation to the line. The corals possess a radiated structure. The very essence of our idea of a coral is to refer it to a line of growth, and to imagine a radiated structure, more or less complex, surrounding that axis of growth round which it developes itself. This, you observe, is going back to a form of symmetry which we found in the vegetable kingdom.

It may now occur to you that the geometrical *forms of the* various kingdoms of nature give us

very little clue or indication as to the relative degree of importance, or of developement in the scale of creation of the creatures that possess them. In fact, as I said before, the highest forms of mathematical symmetry are developed in the lowest kingdom of the three. The symmetry of the line, which is a more complex symmetry than that relating to the plane, is found exclusively in the vegetable kingdom, and in the lower forms of animal life; and it is not till we come to the higher forms of life that we find the geometrical idea of symmetry reduced to a simple symmetry of two sides of the body referred to a single plane; and that plane, as in the case of the higher animals, not having any line in it, or perpendicular to it, round which the symmetry is compelled to take place. It therefore appears to me to be at first sight an indication rather of a low than of a high degree in the scale of creation, to possess great perfection of geometrical form; and therefore I should be disposed, in discussing the subject now before us—the geometrical instincts of animals—to lay down a principle which is in opposition to the opinion of many of the ancient philosophers, that it is by no means to be regarded as a high proof of intelligence in a creature to find it capable of constructing habitations, or making structures of various kinds in accordance with the strictest and most accurate laws of geometry. We shall find, I think, on investigation, that neither the extravagant laudations of the instincts of those animals, nor of the skill, greatly exceeding that of the highest mathematicians with which they are said to construct their habitations, are well founded; nor, on the other hand, do I think you will find reason to believe that the lan-

guage, bordering on a contempt quite inconsistent with their professed disbelief in His existence, with which the Creator of those creatures has been spoken of by many modern naturalists for having endowed them with these geometrical instincts, is justified by the facts. An importance which they do not deserve has been attached to these geometrical forms by both parties in the controversy; and it justly surprises one to find with what animosity a discussion, as to whether the bees or the inventors of the differential calculus were the best mathematicians, was carried on in the last century.

In my opinion, L'huilier solved the question satisfactorily, by producing a form of cell which excelled that of the bee in all the points that were supposed to be essential to its perfection. The same idea, I think, existed among the ancients, because we find in the introduction to the fifth book of the celebrated Pappus, that he also solves the problem of the bees, speaking of them with great respect, but at the same time maintaining that the geometers of his day were able to solve the problem of economy of wax with a degree of perfection to which the bees could not attain. A short history of this question, I believe, will prove to be of some interest, because, if we can satisfy ourselves as to the true theory of the cells of the bees, which has been made for 2000 years the battle ground of this controversy, we shall have no difficulty in solving other corresponding problems respecting the geometrical spider, and the forms which some other animals and corals assume when in contact with each other. The first person, as far as we now know, who attempted the solution of this curious problem, and wrote on the subject of the cell of the bee, was

Pappus. The following is an accurate translation from the introduction to his fifth book :—

"God has imparted to men, indeed, the best and most perfect knowledge of wisdom and discipline; and has assigned to some animals, devoid of reason, a certain portion. To men, therefore, as making use of reason, he has permitted that they should do all things by reason and demonstration, but to other animals without reason, he has given the possession of what is useful and conducive to life, by a certain natural providence.

"Any one may understand this to be so, as well in many other kinds of animals, and more especially in bees. For order, and a certain admirable deference to those who rule in their republic, ambition, moreover, and cleanliness, heap together an abundance of honey; but their foresight and economy concerning its conservation are much more admirable—for holding it for certain, as is just, that they carry back some portion of ambrosia from the gods to choice men, they pour out this, not rashly on the ground, or into wood, or any other unformed and misshapen matter; but collecting from the sweetest flowers that grow in the earth, they form from them most excellent vases as a receptacle for the honey (which the Greeks call *κηρία*, and the Latins *favi*), all indeed equal, similar, and cohering among themselves, of the hexagon species. Now it is thus evident that they construct these by a certain geometrical foresight; for they consider it fit that all the figures should cohere together and have common sides, lest anything, falling into the intervening spaces, should spoil and corrupt their work.

"Hence, three rectilinear and ordinate figures

can effect what is proposed—I mean ordinate figures which are equilateral and equiangular, for ordinate and dissimilar figures did not please the bees themselves. Now, equilateral triangles, and squares, and hexagons (neglecting other similar figures filling space), may be placed next each other, so as to have common sides—other ordinate figures cannot; for the space about the same point is filled, either by six equilateral triangles, or by four squares, or by three hexagons—but three pentagons are less than sufficient, and four are more than sufficient to fill the space round a point—neither can three heptagons be established, so as to fill the space round a point.*

"The same reasoning will apply much more to figures having a greater number of sides. There being, then, three figures, which, of themselves, can fill up the space round a point, viz., the triangle, the square, and the hexagon; the bees have wisely selected for their structure that which contains most angles, *suspecting, indeed, that it could hold more honey than either of the others.*

"The bees, forsooth, know only what is useful to themselves, viz., that the hexagon is greater than the square or triangle, and can hold more honey, an equal quantity of material being employed in the construction of each; but we, who profess to have more wisdom than the bees, will investigate something even more remarkable, viz., that of plane figures which are equilateral and equiangular, and have equal perimeters, that is always the greatest which consists of most angles, and the circle is the greatest of all, provided it be included *in a* perimeter equal to theirs."—*Pappus.*

* *The proofs* of this assertion are omitted in this translation.

Thus we see that Pappus originated the idea of economy of wax; for if we can make cells having a common side so that each wall shall serve for two cells, we shall at once attain an economy of fifty per cent. Here we have an anticipation, by two thousand years, of the conjecture of Reaumur, that economy of wax was the reason for the form of the cell, and the question rested in the condition in which it was left by Pappus until the year 1712, when Maraldi, an Italian geometer, again took up the problem, and carried it a step farther than Pappus had done.

The cells of the bees are hexagonal, and disposed in two rows, which are placed back to back. In this respect they differ remarkably from the cells constructed by wasps. In the latter we have the hexagonal cells placed side by side, and terminating at the bottom either in a flat surface, or in a rudely conical point. The bees' cells are formed in double rows, one set of hexagonal columns opening on one side, and the other on the other, the hexagons of each side being fitted into three hexagons of the opposite side. This structure, by which the hexagonal cells on one side are made to fit into those on the other, has given rise to a controversy that has now lasted for 150 years; and there has been recently a good deal of attention attracted to it by Mr. Darwin, who has revived it again without adding much to it. Maraldi found that the bottom of each hexagonal cell did not meet the opposite hexagonal cell. At first sight one would suppose that each hexagonal cell would be set down against its opposite, and a partition made in the middle. But this, as Pappus would say, did not please the bees, because it

would be equivalent to making a hexagonal cell twice the length that they were in the habit of making them. The bottom of each cell, however, consists of a trihedral angle; therefore, as you look down into each cell you observe three planes, each having the form of a rhombus. Maraldi observed that the rhombus had a definite shape, from which it never varied in the slightest degree; and having observed this curious fact, he was led by it to form a theory as to the manner in which the bees build their cells, which is rather singular. His theory requires us to suppose that it was convenient for the bees to be obliged, considering that they are animals of limited intelligence, to carry the idea of only one angle in their minds; and that the Creator has, therefore, endowed them with the faculty of forming an idea of an angle of $70^\circ\ 31'\ 44\frac{1}{4}''$, which is the angle of the rhombus of which they make the ends of the cells. He supposes that each bee endowed with the wonderful instinct of carrying this angle in its mind is never satisfied with its work until it shapes the wax to that angle; so that we may regard each bee constructing his cell on Maraldi's principle, as provided with a sort of mental plumb line by which he regulates his work, and equals it to the angle with the idea of which the Creator has endowed him.

Maraldi considered that he had made great progress in the question when he found that he could reduce all the angles requisite for the construction of the cells to one; but it remained for the naturalist Reaumur to add a most unfortunate complication to this problem. Reaumur suggested to his mathematical friends whether it might not be possible that by the construction of the bottom of

the cells in this trihedral form, an economy of wax takes place similar to what is found to occur in the original hexagonal construction of the cells which had been noticed by Pappus. M'Laurin, the famous Scotch geometer, solved this problem in 1743, and satisfied Reaumur, and naturalists in general, that there was an economy of wax. It turned out as a remarkable fact that by the particular angle employed by the bees a further economy of wax was produced. To me this economy of wax appears so contemptible, that I think any person that can suppose it to have an influence in the construction of the cell must have a mind constituted like that of a poor-law guardian. Two per cent. is all that it is possible to save by this particular angle.

In 1781 the celebrated Genevese mathematician, L'huilier, took up the question again in the spirit of Pappus. He quoted the introduction to the fifth book of Pappus, and said he agreed with Pappus that the intelligence of man was greater than that of the bee; and in so doing, said he was not to be supposed to accuse the Creator of the bee of any want of intelligence, if he denied *in toto* the whole theory of the geometrical instinct which was supposed to influence the result. He accepted the challenge of naturalists with regard to the economy of wax, and furnished mathematicians and naturalists with a form of cell which, if the bee would only take the trouble to construct, he might economize a much larger proportion of wax than two per cent. He naturally objected to two per cent. as influencing the result, and provided the bees with a shape of cell which would enable them to make five cells for each four that they now

make, which would be a saving of wax of 20 per cent.

The question rested from 1781 until it was revived in late times by some speculators, who arrived at another extraordinary property attained by this form of the cells of the bee—namely, that it was the figure that had the mechanical property of offering a maximum resistance to fluid pressure. It so happens that the planes of the cell make angles of 120° with each other, which is well known to mechanicians to be the best angle for a pair of lock gates to resist pressure. From this fact, some have come to the conclusion that not only was economy of wax one of the objects in the construction of the cell, but that a maximum of resistance and strength was also accomplished in its form. But when you consider that the only pressure that can come upon these floodgates is a pressure not exceeding a line and a half of fluid, because these cells are placed horizontally, such considerations as to the strength of the cell must be supposed to have no part in the problem; moreover, in the outside end of the cell, which is simply plugged with a bit of wax, we have the worst possible form of structure for resisting pressure; therefore it is evident, to my mind at least, that the strength of the cells can have no influence whatever in their formation.

Mr. Darwin, in his book on the "Origin of Species," has revived the question again, and has converted the economy of wax into a motive force sufficient to create the bee. His theory is, that in the construction of the cell the bee is guided by no instinct. In that I agree with him to a certain extent—namely, that the instinct is not of that *mathematical kind* which has been assigned. But he

supposes that a set of bees having by some chance or accident hit off this particular form of cell which involves an economy of wax, and the practice of making such cells having become hereditary amongst them, those bees, as a necessary consequence, had a natural advantage in the struggle of life, which enabled them to maintain their ground, and to destroy in the competition for food other races of bees. It appears to me that neither the wonder of the natural theologians at the geometrical talents of the bee, nor the extraordinary theory of Darwin, which converts this geometrical form into a motive force sufficient to create the animal that made it, is worthy of our attention. We find our common British wasp making hexagonal cells without these remarkable forms at the bottom. He has not the intelligence to perceive that, if he placed his cells back to back, he could avail himself of M'Laurin's famous two per cent. If he put them back to back, he could construct them, with the help of the wasps on the other side, in the form of a rhombic dodecahedron, and would then be rewarded with two per cent. of material, and would, besides, have the satisfaction of feeling himself more intelligent, more perfect in his faculties, more improved than his neighbours, and altogether a more highly civilized order of wasp. The wasps of Madagascar are just as ignorant as the British wasp. They make hexagonal cells, but stop up the ends by figures of no geometrical shape at all, and there is no attempt made by them to place the cells back to back. The wasps of Mauritius, also, have the same unenlightened, unintelligent mode of constructing their habitations.

It is worthy of inquiry whether these structures

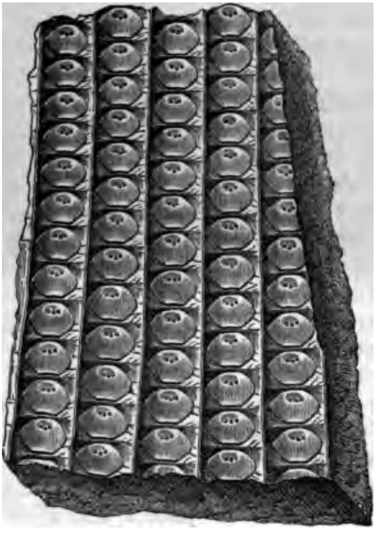
are the result of geometrical instincts implanted in the creature, as the ancients supposed, or of any such fantastic notion as economy of material; or whether the idea of either economy or strength of material should enter into our investigations of their form. I believe that the geometrical forms of such structures as wasps' cells, bees' cells, and many other cases to be mentioned, even the microscopic cells of many plants, and the cellular tissues of animals, may be explained without any reference either to instinct or to the attainment of economy or mechanical strength. If a large bomb-shell be filled with musket bullets, fired against a bank of earth, and then broken, the bullets when taken out will be found converted into pentagonal dodecahedrons; and the facets appearing upon each bullet will be pentagons, of course some being more, and some less perfectly indented to this shape. This remarkable geometrical form would be acquired by each bullet simply from the pressure of all the rest against it when the shell strikes against the wall. This form is well known to be one of those which the ancient geometers called perfect forms, from their being capable of being inscribed in a sphere, and which are only five in number. Any one wishing to try the experiment may do so, without the trouble or expense of a bombshell full of bullets, by going to a chemical laboratory and examining the froth which rises on the top of an organic solution. The bubbles composing this froth are spheres; and these spheres collect together in great quantities, forming a large portion of the top. If you examine the froth while the bubbles of air press on each other, you will find that the contact and the pressure compel the spheres to

assume pentagonal faces. Suppose for a moment that these bubbles or bullets were the result of the organic labour of some creature, would we for a moment think of ascertaining the physical properties of a pentagonal dodecahedron, and then ascribing to those physical properties the production of the animals that made such forms? Certainly not. In the case of the hexagon, wasps and the bees are endowed with an instinct—which I regard as an ultimate fact—of constructing the cells side by side with each other. The bees have an additional instinct of constructing a double row of cells, which the wasps do not possess. These two instincts I regard as ultimate facts, and profess not to be able to explain them. But the moment the wasp is taught to build his cell side by side with those of other wasps, the cells must assume a hexagonal form, being compelled to that by their mutual pressure upon each other. If we suppose a number of spheres to be contained, not within a spherical shell, but within a cylinder, and that cylinder gradually to close upon the spheres towards its axis, the spheres will all assume the form of elongated hexagonal prisms. If we now consider the successive rows of spheres, each will fit naturally into the hollow of three spheres, and if we suppose the ends of the cylinder to approach, so as to produce a contraction in the direction of the length of the cylinder, we shall have produced in the spheres precisely the form of the bee's cell—a prism with hexagonal sides; and its ends will be necessarily the planes of a rhombic dodecahedron.

The tendency to hexagonal arrangement of parts growing, or built up, in contact with each other is not confined to the animal kingdom; as may be

well seen from the hexagonal leaf scars of Fig. 3, which represents the *Sigillaria tessellata* of the coal period, whose growing leaves, pressing on each other, have been compelled to assume the hexagonal form.

FIG. 3.



SIGILLARIA TESSELLATA.

This form may be also well seen in the bones of the paddle of the *Ichthyosaurus*.

I have chosen these two instances of pentagonal and rhombic dodecahedrons to illustrate my meaning. We do not know of any organic creatures that form pentagonal dodecahedrons; but we can *conceive* the conditions under which they would

do so; and in such a case we should not ascribe to a geometrical instinct imparted to the animals the tendency to make these forms, as the ancients would have done; nor ought we, as some of the moderns have done, to seek in the geometrical and mechanical properties of these forms, the reason for their being made. As I have already said, it appears to me that there is no connexion whatever, except perhaps one of an inverse kind, between these geometrical forms and the instincts or the intelligence of the animals that make them; and that our wonder at the beauty of those forms must not be allowed to attach itself in any way to the animals that have made them, as if they possessed intelligence superior to their neighbours. According to the language of the Lamarckian school, the bee would possess some perception of the advantage of this form, and therefore would make it. This was the opinion also of the ancients, as I have shown. According to the opinion of the Darwinians—the more modern school—the bee would possess no such knowledge of the form; but the natural physical advantage of that form would cause it to continue to be made by the bees amongst whom the habit of making it had become hereditary. Both these views we have reason to consider to be completely erroneous.

LECTURE VIII.

PROTOZOA — FORAMINIFERA — NUMMULITES — RECEPTACULITES NEPTUNI—SPIRAL OF ARCHIMEDES—FOSSIL SPONGES —CŒLENTEROZOA—FOSSIL CORALS—DEVELOPEMENT OF SEPTA—ZOANTHARIA— RUGOSA — ALCYONARIA — ENTOMOZOA — ORDERS OF CRUSTACEANS —PODOPHTHALMS — COPEPODS — OSTRACODS — TRILOBITES—EURYPTERIDS — PALÆONTOLOGICAL LAWS.

IN the last Lecture I directed attention to the geometrical laws that regulate forms in the mineral, vegetable, and animal kingdoms, and I endeavoured to show you that the more perfect its subjection to geometrical laws was, the lower was the creature in the scale of organization; so that we have the most complex geometrical laws exhibited in the mineral kingdom, less complex geometrical laws in the vegetable kingdom, and in the animal kingdom, particularly its highest developements, we have the symmetry of form reduced to its simplest condition, that of a bilateral symmetry with reference to a plane, all symmetry with reference to a line having been abandoned. In following out this subject I directed your attention also to the geometrical tendencies which certain organized creatures exhibited in their instincts, and showed you what I believed to be the true explanation of such geometrical tendencies—that they are not to be considered either in the light of special instincts with which the creatures are endowed, nor, on the

other hand, are they to be regarded as motive forces capable of influencing the progress of the organization of the creature itself.

In the present Lecture we shall commence the history of the animals that lived at various times upon the earth's surface; and we shall find as the result of our investigation that there is a general progress in complexity of organization as we follow the history of the globe from the oldest to the newest strata, although there are many exceptions. I shall begin by inviting your attention to the general history of the Protozoa, the Cœlenterozoa, and the Entomozoa.

The Protozoa are divided by naturalists into the following classes:—

SUBKINGDOM PROTOZOA.

CLASSES.	*Fossil Orders.*
I. GREGARINES, ... (Grex),	*None.*
II. RHIZOPODS, ... (τὰ τοὺς πόδας ῥιζώδεις ἔχοντα),	1. *Foraminifers.* 2. *Polycystines.*
III. SPONGES, ... (σπογγιαί),	3. *Sponges.*
IV. INFUSORIES, ... (Infusum),	*Doubtful.*

With the first and last of these classes the geologist has little or no concern; but the second and third contain many extinct forms of great interest.

According to Dr. Carpenter, the Rhizopods should be divided thus:—

RHIZOPODS, ... 1. Lobate,
2. Radiolate.
3. Reticulate.

The lobate Rhizopods are not represented by any fossil forms; the radiolate Rhizopods contain the Polycystines; and the reticulate Rhizopods include all the forms known as Foraminifers.

I. Foraminifera.—Belong to the Rhizopod Protozoa, and are of exceeding interest to geologists, although it has been only within the last few years that their great importance has been recognised as it deserves. The Foraminifers belong to that group of the Protozoa which are capable of forming cells possessed of a stony consistence, so that, after the death of the animal, the series of cells which it formed when living are preserved fossil, thus giving us an evidence of their existence and of their structure that no animal which is composed altogether of soft parts can give. An immense variety of these Protozoa are known. Some of them, as I explained in yesterday's lecture, form their cells in a right line. Others have the property of forming their cells in continuous spirals, so that from the centre to the circumference, the structure of the animal is simply a succession of cells, arranged in a spiral line; and in a third group, the cells are arranged irregularly.

The Foraminifers are divided as follows:—

Suborders.	Families.
I. Imperforatæ, ...	1. *Gromiidæ.*
	2. *Miliolidæ*, Fig. 2, *g*, *g'*.
	3. *Lituolidæ.*
II. Perforatæ, ...	4. *Lagenidæ*, Fig. 2, *a*, *a'*, *b*.
	5. *Globigerinidæ*, Fig. 2, *e*, *f*.
	6. *Nummulinidæ*, Fig. 2, *c*, *d*; Figs. 4 and 5.

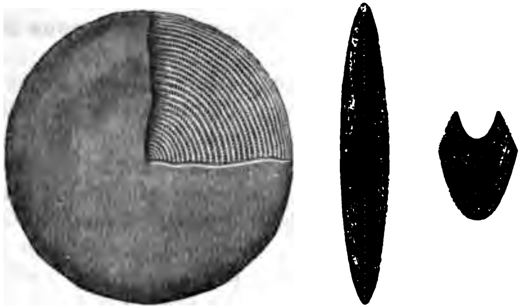
Each of the cells is occupied by a sarcode substance, which appears to be exceedingly simple in its structure, and which is endowed with the property of producing another cell at its extremity according to a fixed law of developement.

The last Family has been known to geologists

for a long time under the name of Nummulites. In fact, so well known and so widely spread are these Nummulites, that they have given a name to a particular limestone.

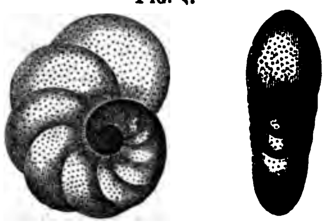
The accompanying woodcut, Fig. 4, shows the structure of the Nummulite, which consists of a succession of distinct cells, arranged in a plane spiral, and the whole coated over by a calcareous shell. It is quite certain that the nummulite, like other Foraminifers, was an individual animal, and not a congeries of individuals, like many of the Cœlenterozoa. The cells communicated with each other by means of a minute pore, which is shown in the magnified view of a portion of the cross section.

Fig. 4.



NUMMULITES COMPLANATA.

Fig. 5.



NONIONINA BATHYOMPHALA.

In Fig. 5 we have an admirable specimen of the

nautiloid character of the shell of *Nonionina bathyomphala*, one of the Foraminifers of the tertiary beds of Vienna. It is not to be wondered at that even observers like Linnæus, Cuvier, Ferussac, and Lamarck should have placed animals possessing shells like this among the Cephalopods.

There are 52 species of nummulites recognised by geologists, and all of these are characteristic of a period intermediate between the Cretaceous and the Tertiary.

The geographical distribution of nummulites is most remarkable, as they are found along the entire line of mountain chains from the Pyrenees to Tibet, and occur at all altitudes, from 8000ft. and 10,000ft. in the Pyrenees and Alps to 15,000ft. in the Himalayah Mountains; they form a geological zone stretching W. N. W. to E. S. E., from 10° W. long. to 55° E. long., having a width of 1800 miles; further to the east it narrows considerably, but the entire length from W. to E. embraces 98° of longitude, and its breadth, from N. to S., ranges from the 16th to the 55th degree of north latitude. The nummulitic limestone surrounds the entire border of the Mediterranean Sea and of the Black Sea. It constitutes a large portion of Egypt and of Asia Minor, and the nummulites of the Pyramids attracted the attention of Strabo, who had been familiar with them previously as an inhabitant of Asia Minor. The desert soil trodden by the Israelites, in their Exodus to Sinai, was principally composed of these fossil Protozoa. Strabo thus writes of the nummulites of Egypt:—"We do not think it fit to pass over in silence a singular thing which we saw at the Pyramids, viz., the heaps of chipped stone (λατύπης), *that lie in* front of these monuments. There are

among these fragments (ψήγματα), some that in form and size resemble beans, one would say with the skin half removed. These are said to be the petrified remains of the food of the workmen; but this is very improbable, for in our own country there is an oblong hill in the middle of the plain which is full of bean-like pebbles, made of a white porous lime stone."*

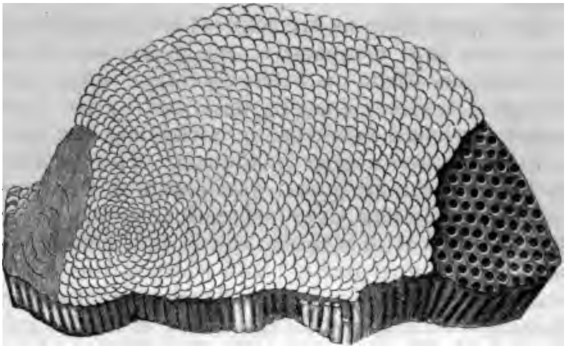
But, interesting as are some of the nummulites, they sink into comparative insignificance, when we compare them to a closely allied form, the *Eozoon Canadense*, recently described by Dr. Carpenter, as found occurring in rocks near the base of the Laurentian series in Canada. The massive skeletons of this Rhizopod would seem to have extended themselves over submarine rocks—their base upwards of 12 inches in width, and their thickness from 4 to 6 inches; and while at this early period we thus see so large a developement of the Perforate suborder of Foraminifers, it is also curious to find that among the Imperforate type, early in the Palæozoic age, we meet with disks of Receptaculites of about a foot in diameter, although the largest recent species never exceed an inch in diameter.

This latter fossil has long perplexed the geologist, and is well known under the name of Neptune's Receptacle, *Receptaculites Neptuni*, whose zoological affinities have been much disputed. It is found somewhat abundantly in the Grauwacke formation of the Rhine, and in the Upper

* Strabo, Geography, lib. xvii., p. 808: Paris, 1620. Strabo was a native of Amasis, in Pontus, a locality in the neighbourhood of which Tchihatcheff has recently found a fine series of nummulites.

Silurian beds of North America, belonging to the Trenton period. The specimen from which the following figure is partly drawn was found by Capt. Sir Leopold M'Clintock, in a cream-coloured dolomite, in King William's Land, during the "Fox" expedition in search of Franklin:—

Fig. 6.



RECEPTACULITES NEPTUNI.

Many geologists have considered it to be a fossil plant, and have compared its lozenge-shaped markings with those of the Lepidodendra. On examining these markings carefully, however, it will be observed that, although they are arranged in quincunx, like those of Lepidodendra, yet there is a peculiar spiral effect produced by their arrangement, converging towards a centre, like the turning on the back of a watch.

At one time the *Receptaculites Neptuni* was supposed to be the fossil remains of the scales of some unknown fish.

Mr. Salter and Dr. Carpenter have succeeded in

showing, with much probability, that it is a fossil Rhizopod, of proportions that may justly be considered as gigantic, when compared with those of its modern congeners.

The modern form with which Mr. Salter compares it is the Orbitolite, which is a Rhizopod growing from a central nucleus, by successive rings of growth, each furnished with a certain number of equidistant cells, connected by a filament of sarcode; and the successive rings follow each other in such a manner that the cells of each are intermediate to the cells of the two adjacent rings. I have already shown you that the quincuncial arrangement of the leaf scars in many fossil plants is explained by the fact that the leaves may be imagined to be placed on a series of parallel lines, so as to alternate with each other; and when these parallel lines are wrapped round a cylinder, the leaf scars seem to be arranged helically on the stem of the plant.

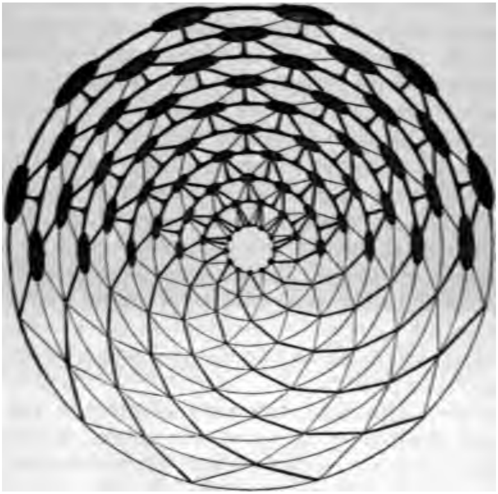
In the Orbitolites, the cells of sarcode are arranged alternately on concentric circles, instead of parallel lines, and, as a necessary geometrical consequence, these cells appear to the eye to be arranged in Spirals of Archimedes, both right and left-handed. In the following Fig. 7 I have drawn an ideal section of the Orbitolite, whose circle cells are twelve in number; and in the shaded portion of the figure, the black spaces represent the sarcode substance in cells and connecting stolons.

I have made the circles equidistant from each other, an arrangement which causes the spirals to be those of Archimedes, which immediately catch the eye, and produces the appearance of engine-turning, that makes the structure of Nep-

tune's Receptacle to differ from that of the Lepidodendra.*

I must here call your attention to a law which we shall find constantly developed in our study

FIG. 7.



IDEAL ORBITOLITE,
Showing Spiral of Archimedes.

of the history of life on the globe, namely, that, whatever be the department of zoology we are considering, we often find among the earlier representatives of that form of existence on the globe, creatures, that in size and proportions greatly ex-

* The Spiral of Archimedes is only a particular case of the class of spirals whose equation is $\rho = A\,\omega^n$ when $n = 1$. It seems to me that in the *Receptaculites Neptuni* the radius vector increases *faster* than the angle.

ceeded those that are now living. This law, as I have shown you, is true of the Foraminifers. We shall find it to be conspicuously true of plants, reptiles, birds, and mammals. In fact, it appears to be an almost universal law of the developement of life on the globe, that each group of organic beings increased in size and in importance in an uninterrupted line from the commencement of its existence, until they reached their maximum in some short time—I mean short as compared with their whole life history—after their original creation and appearance upon the globe; and it would almost seem as if, having reached that maximum of developement, they then commenced a process of degeneracy and decline.

II. Polycystines.—The Protozoa referred to this order differ from the Foraminifers in having siliceous, and not calcareous shells; and these shells are usually of smaller size than those of the Foraminifers, and are remarkable for the great beauty and variety of their forms. They are essentially marine animals, and appear to have lived in former times, as they do now, at the bottom of deep seas, associated with Foraminifers and Diatomes. The Polycystines have been studied in detail by Ehrenberg, who has described numerous forms, both recent and fossil. The so-called "polishing slate" of Bohemia is composed of innumerable carapaces of microscopic animals, some of which, undoubtedly, belonged to the Polycystines, and are analogous to the siliceous shields or cases of living Protozoa of this order. Similar beds of "polishing slate," known in commerce by the name of "Tripoli," are found in Germany, Sweden, France, Mauritius, North and South America, and the eastern parts of

Asia, and are composed, for the most part, of the remains of Polycystines, which, however, are not of many species, for, frequently, there are not more than three or four species in thick deposits.

III. Sponges.—The Sponges are now universally recognised as members of the Animal, and not of the Vegetable Kingdom of Nature. They are interesting to the geologist from the fact, that the great majority of them form a skeleton, composed of fibres of a horny texture, supported by spiculæ of siliceous or calcareous matter, and this skeleton is frequently found fossil, the gelatinous or animal portion of the body of the Sponge having undergone decomposition.

These sponge-skeletons illustrate a theory of fossilization to which I formerly called your attention; containing as they do siliceous spiculæ in their interior, they form a centre, round which siliceous matter in solution in the sea water collected, so as to form the nuclei of many of the flints that are found in the cretaceous, oolite, and other rocks.

The Sponges are divided by geologists into three Families:—

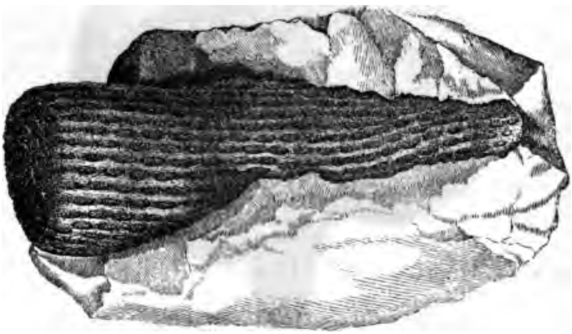
1. SPONGIDÆ.—Having a horny skeleton, supported by a network of spiculæ, either siliceous or calcareous; attached to rocks and other substances.
2. CLIONIDÆ.—Boring Sponges, of a structure similar to last.
3. PETROSPONGIDÆ.—Having a stony skeleton, without spiculæ; altogether fossil.

Of these families, the first two, having horny skeletons, perished almost altogether in the destructive process of fossilization, and are therefore comparatively unknown to the geologist.

The Petrospongidæ, on the contrary, are unknown *to zoologists*, while they are abundant in all the

strata, from the Silurian to the Nummulitic, when they seem to have disappeared from the globe. They differ so much from the other sponges, that their classification is founded altogether on trivial characters, of the relative physiological importance of which we are ignorant. Many of them are amorphous; but a large number are cup-shaped, and contain an internal cavity, which, as well as the outer surface, is covered with oscula, or pores, more or less regularly arranged, and which give rise to specific distinctions. The accompanying Fig. 8 represents a species of *Ventriculites*, from

FIG. 8.



VENTRICULITES—COUNTY OF DERRY.

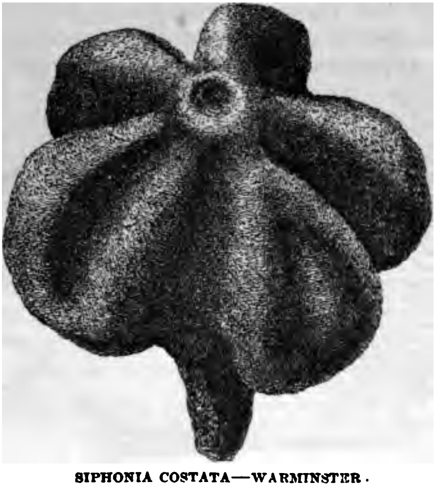
the chalk of the county of Derry, and illustrates well the general arrangement of the oscula in the group to which it belongs.

Fig. 9 represents the *Siphonia costata*, from the greensand of Warminster, and shows the manner in which many of the Petrospongidæ grew from a stalk attached to some fixed point at the bottom of

the sea. The *Siphonia* was also provided with a central tubular cavity, at the apex, which was lined with regularly distributed oscula, the use of which is only approximately to be determined from an examination of living Sponges.

Many of the amorphous Sponges of the older rocks have been confounded with the Corals and

FIG. 9.



SIPHONIA COSTATA—WARMINSTER.

Polyzoa, with the first of which the Petrospongidæ had close relations. As an example of this confusion, I may mention the *Stromatopora* and *Tragos* of the Silurian and Carboniferous periods.

The Subkingdom—Cœlenterozoa—which next demands our attention, is divided by modern naturalists into two great groups, the Hydrozoa and

Actinozoa. The Hydrozoa are composed almost exclusively of soft parts, and therefore the geologist knows little concerning them. The Actinozoa, however, contain all the corals which, in consequence of their calcareous skeletons, are capable of being preserved in limestone rocks, and they are of the highest interest to us.

The name of Radiata (*Cuvier*) is most accurately applied to this important group, as their geometrical symmetry consists in their relation to a single line. They radiate from a central line in various manners; and whether we regard the sea nettles or the polypes, we shall find the simple law of radiation from a fixed central line predominating in the great majority of them. One of the good reasons that I believe exists for separating the Echinoderms from the Radiata is, that in all the Echinoderms you find symmetry with reference to a plane, and not merely with reference to a line. You can assign the right and left side of an Echinoderm; but the terms right and left side, as applied to a Cœlenterate, would be frequently erroneous. They have an upper and an under surface, if you like, according to the point of attachment; but they have no right or left. Their symmetry is of the humbler character, related to a line, and not to a plane, although, as I have already explained, symmetry with reference to a line is more beautiful in a geometrical point of view, and more complex, than symmetry with relation to a plane.

If we examine either Hydrozoa or Actinozoa, we shall find this symmetry clearly expressed in the manner that I have said. In the soft-bodied Actinozoa the radiating planes are organic, and you may see them clearly visible in the animal through

its transparent covering; and in the corals these radiating planes start from central axes of symmetry, and are endowed with the property of secreting carbonate of lime, so as to form the stony skeleton of the coral by means of that secretion.

If a cross section be taken of the upper portion of a single actinozoon in the coral, we shall find the lower portion consisting of stone—carbonate of lime, which is developed in radiating planes passing through a line of symmetry; and many corals are also divided by horizontal planes, which are developed from time to time as the animal grows. The upper part of the coral resembles an ordinary polype, its single digestive canal opening into a somatic cavity, which is provided in these animals, which are of a higher organization than the Protozoa, with a reproductive organization. The whole of the upper part of the coral is therefore living; but we have learned latterly to believe that the body of the coral is also living—as truly living as the skeleton of so humble a creature can be said to live. The skeletons of man, and of the higher animals, are obviously living, because we see them supplied by nerves and blood-vessels, and the injury of them causes pain, and they are capable of inflammation. But it is not so obvious that the stony, almost mineral, skeleton of a coral, is also part of the animal itself. There can be now no doubt, however, that this is the case, and that, although it is not capable of feeling pain, it yet constitutes a part of the animal; and this is the reason why the fossil coral has so high a zoological importance, namely, that in the divisions and plates of the skeleton preserved to us in a fossil condition we obtain information as to the history of the soft parts of the

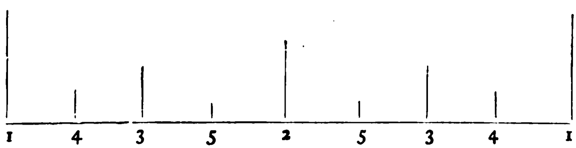
polype that produced it. The divisions that radiate from the circumference to the centre are called *septa;* and the divisions that occupy a horizontal position are called *tabulæ*. Annexed are the various orders:—

SUBKINGDOM CŒLENTEROZOA.

CLASSES.	*Fossil Orders.*
I. HYDROZOA, (ὑδροζῶα,)	1. *Milliporidæ.* 2. *Medusidæ.*
II. ACTINOZOA, (ἀκτινοζῶα,)	1. *Zoantharia.* 2. *Rugosa.* 3. *Alcyonaria.*

Of the Actinozoa, it is to be observed that the *Rugosa* are exclusively fossil, the *Zoantharia* and the *Alcyonaria* are partly fossil and partly living; and that a fourth order, the *Ctenophora*, are wholly living. In the growth of these corals a remarkable developement, subject to geometrical symmetry, takes place. The whole coral is developed with regard to a central axis, from which radiate planes in various directions; and we may divide the *Rugosa*, which are corals exclusively fossil, from the Zoantharia, by means of these radiating planes. The Rugosa are all divided by four planes; the others by six, and sometimes five; and in the developement of these planes a remarkable law of geometrical symmetry, controlled by vital force, takes place. Let us suppose that we are dealing with a Rugose coral. We may find Rugose corals in which the *septa*, or divisions starting from the circumference, do not meet in the centre; at least in the young animal they do not meet in the centre, but as the animal grows older, the lower parts of the septa grow on and meet in the centre, often

forming a kind of twisted bundle of stone, which follows the growth of the animal in its cup-shaped cavity. Let us call these divisions primary, and designate them by the figure (1); and let us remember that the same description applies, *mutatis mutandis*, to the Zoantharia, in which we have subdivisions of 6, and sometimes 5. Now, as you might expect, these quadripartite divisions having taken place in our Rugose coral, other divisions bisecting the quadripartite will appear. These we shall call (2). So far the law of symmetry is perfect, and the next subdivision is also perfect, namely (3). Up to that point the developement of the symmetry is complete; the quadrant is bisected, divided, and bisected again. And now, when we would expect of the subdivisions of the animals that its *septa* should proceed further in the same way, and that these angles of $22\frac{1}{2}^\circ$ should be again divided into the points of the compass, we shall find ourselves disappointed. The law now appears that the intervals next the primary *septa* are bisected, so that the fourth series of subdivisions is confined to the second halves next the original septa.



Then, at a later period in the life of the animal the next series of subdivisions appears (5), corresponding to the omitted parts. Therefore, as soon *as you pass* the third subdivision, the fourth does

not occur symmetrically, but it requires the fourth and the fifth divisions together to produce a complete subdivision. In general, if we wish to predict the further subdivisions; the new *septa* will appear again in the spaces next the oldest; and the general law, although complex at first sight, is easily expressed—the new *septa* always appear in the subdivision, the sum of whose adjoining numbers is the least. This remarkable and unexpected law of geometrical developement of corals was brought to light by the researches of Milne Edwards and Haime. It forms an exceedingly curious and beautiful law, showing the manner in which vital forces preside over the growth of the animal coral, although governed themselves by a geometrical restriction. The animal appears unable to form all the septa which represent the number required by the rigour of the geometrical law; and therefore the act of making those septa is divided, in the growth of the animal, into a number of successive efforts, these efforts, each accompanied by a fresh creation of stony skeleton, being performed in succession by the parts of the animal that have rested for the longest time after each growth. This is what we would expect if we were to predict their formation; at least, after we are made aware of the facts, it is the theory that seems to suit the case.

With regard to the size of the fossil corals, we have no such remarkable law developed in their history as in the history of the Protozoa and other animals. We do not find that any of the ancient corals exceeded in size the modern corals; and, in fact, if we were to select a group of life that has held its way from the commencement to the present time without showing any great signs of degradation, or of progress, or of movement of any kind,

either upwards or downwards, we should select the corals. At the same time, we must remember a most important fact respecting them, that appears in many other branches of the animal kingdom, namely, that the whole group of Palæozoic corals differs as a class from the Neozoic corals, including the living corals in the latter.

I. Zoantharia.—This order of Cœlentera is divided into three suborders :—

1. Zoantharia malacodermata.
2. Zoantharia sclerobasica.
3. Zoantharia sclerodermata.

Of these suborders, the third only possesses a true calcareous skeleton, and is therefore the only order that is met with in the fossil condition.

The Zoantharia are Actinozoa, in which the tentacles and mesenteries are generally multiples of *five* or *six* ; the corallum is either absent, or sclerobasic, or sclerodermic, and it is this character that forms the distinction between the three suborders.

The fossil *Zoantharia sclerodermata* may be readily divided into their eleven families, by means of the following scheme (*Greene*) :—

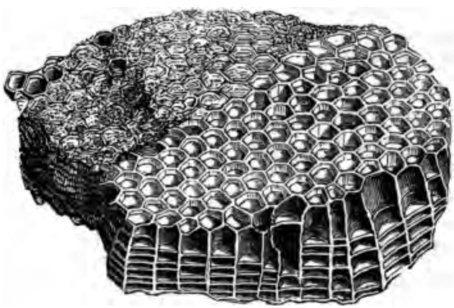
ZOANTHARIA SCLERODERMATA.

1	Tabulæ present. Septa rudimentary (*Tabulata*),	2
	Tabulæ absent,	5
2	Cœnenchyma wanting, or ill-developed,	3
	Cœnenchyma abundant,	4
3	Septa forming a spurious, massive cœnenchyma,	Family 1. THECIDÆ.
	Septa and corallites distinct,	Family 2. FAVOSITIDÆ.
4	Sclerenchyma compact. Corallum arborescent,	Family 3. SERIATOPORIDÆ.
	Sclerenchyma tubular or cellular,	Family 4. MILLEPORIDÆ.
5	Septa indicated by faint striæ (*Tubulosa*),	Family 5. AULOPORIDÆ.
	Septa well developed,	

6	Sclerenchyma porous (*Perforata*).	 7
	Sclerenchyma imperforate (*Aporosa*), ...	 8
7	Sclerenchyma reticulate. Thecæ not distinct from the surrounding cœnenchyma, .	Family 6. PORITIDÆ.
	Sclerenchyma simply porous. Thecæ distinct, ...	Family 7. MADREPORIDÆ.
8	Synapticulæ present. No dissepiments, ...	Family 8. FUNGIDÆ.
	Synapticulæ absent, . . .	 9
9	Dissepiments in general numerous. Cœnenchyma absent, or formed only by the developement of the costæ or epitheca, ...	Family 9. ASTRÆIDÆ.
	Dissepiments few or absent, .	 10
10	Cœnenchyma compact, abundant, ...	Family 10. OCULINIDÆ.
	No cœnenchyma, ...	Family 11. TURBINOLIDÆ.

As an example of Zoantharia, and of the use of the foregoing scheme, I may mention the beautiful coral *Columnaria Franklini*, drawn in Fig. 10, from a specimen brought by Captain M'Clintock, from Cape Riley:—

FIG. 10.



COLUMNARIA FRANKLINI—SILURIAN.
(Portion of corallum, of the natural size.)

On examining the scheme, we find the Zoantharia, in section (1), divided into tabulate and non-tabulate corals. The specimen before us is evidently tabulate, and we therefore follow the reference to section (2), where we find the tabulate corals divided into those with and those without cœnenchyma. As our specimen contains no cœnenchyma, we proceed to section (3), where we find the two families, *Thecidæ* and *Favositidæ*, the latter with distinct corallites, and the former with corallites blended into one mass, and to this family, evidently, the *Columnaria Franklini* belongs.

The order of Zoantharia, whether it be regarded as represented by the soft-bodied Sea-anemones, or by living Corals, is by far the most important of the living orders of Actinozoa; but in former times it yielded in importance to the next order, which is exclusively fossil, and which appears to have differed from the Zoantharia principally with respect to the geometrical type, on which it was developed.

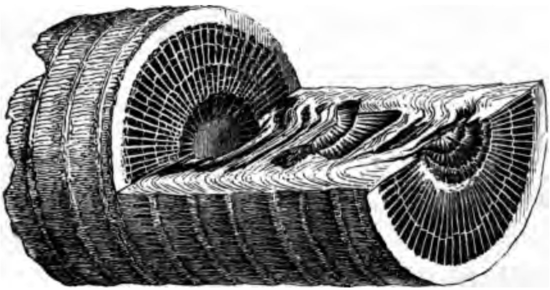
II. Rugosa.—These are sclerodermic Actinozoa, with tabulæ and well developed septa, arranged in multiples of *four*. They are exclusively fossil.

Among the Rugosa a highly developed sclerodermic skeleton occurs, each corallite being very distinct, and presenting, in many cases, both septa and tabulæ. Some *Rugosa* are simple, the corallite often attaining a considerable size; others are composite, increasing either by lateral or calicular gem mation, these two processes, but especially the latter, checking to a greater or less extent the growth of the primitive corallite. A true cœnenchyma is absent.

In Stauria, *Holocystis*, and *Polycœlia* four of the

septa admit readily of being distinguished, by their greater developement, from the others, but in *Cyathaxonia* only one primary septum or chamber remains conspicuous. In other genera, such as *Zaphrentis* (Fig. 11) and its allies, the septa radiate, in about an equal manner, from the inner surface of the theca. In many Rugosa they are incomplete, that is, do not extend from the bottom to

FIG. 11.



ZAPHRENTIS CYLINDRICA—CARBONIFEROUS.
(Part of a corallite, of the natural size.)

the top of the corallite, in the form of uninterrupted laminæ.

The tabulæ exhibit various grades of developement, and, in some species, are wanting altogether.

In a few Rugosa the columella is cylindrical, and of large size; in others, styliform or lamellar: often, it is wanting. In *Cyathophyllum* and certain allied forms there is a spurious columella formed by the twisting together of the inner edges of the septa.

In *Cystiphyllum* neither columella, septa, nor

tabulæ can be distinguished. The whole interior of the corallite, save its shallow calix, is here, as it were, broken up by the numerous laminæ of a sclerenchymatous deposit, resembling the vesicular substance of its epitheca and wall.

Most Rugosa belong to the large group of *Cyathophyllidæ*. The remaining families include but a few generic forms.

Order Rugosa.

Family 1. Stauridæ.
Corallum simple or composite. *Septa* complete, united by lamellar dissepiments.

Family 2. Cyathaxonidæ.
Corallum simple. *Septa* complete. No dissepiments or tabulæ.

Family 3. Cyathophyllidæ.
Corallum simple or composite. *Septa* incomplete. Tabulæ, in general, present.

Family 4. Cystiphyllidæ.
Corallum simple; composed chiefly of a vesicular mass, with but slight traces of *septa*.

III. Alcyonaria.—These are Actinozoa, in which the mesenteries and somatic chambers are some multiple of *four*. The corallum never presents traces of septa.

The Alcyonaria are composite in structure; their polypes being mutually connected by a cœnosarc, through which permeate prolongations of the somatic cavity of each, forming a sort of canal system, whose several parts freely communicate and are, therefore, readily distensible.

Throughout the whole order the polypes exhibit a very close agreement in structure, howsoever much the cœnosarc may vary. Each, when expanded, displays a cylindrical, or somewhat octagonal, tube, with delicate transparent walls, and

eight pinnate tentacula, whose form offers slight though characteristic variations among the several genera of the group. In some the polypes are retractile into excavations which occur in the substance of the cœnosarc, while in others such excavations seem to be wanting.

Alcyonium, the typical genus, presents, when first dredged up, a sufficiently repulsive aspect, suggestive of the vulgar names, "Cow's paps" and "Dead-man's hand," sometimes conferred on it. But, when placed in sea-water, the lobate fleshy mass, distending its aquiferous system, is gradually seen to become exquisitely pellucid, while from all parts of its surface numbers of tiny polypes, emerging, expand to the utmost their star-shaped crowns of delicately fringed tentacula. Within the somatic chambers circulating currents may now be observed. These find their way up one side of the tentacles, following the course of the several fringes, and, having gained their summits, again revert, proceeding in a contrary direction. So that here, as in many *Zoantharia*, it would not, perhaps, be too much to say that the tentacles, by reason of the delicacy of their ciliated walls, fulfil the proper function of a respiratory system.

The beautiful Organ-pipe Corals, forming the several species of the genus *Tubipora*, appear to be the sole representatives of the family of *Tubiporidæ*. The colour of their corallum is, in all cases, of a bright crimson-red. The polypes are either violet or grass-green in tint, and, according to the dissections of Dana, present this anatomical peculiarity, that two only of the mesenteric edges are furnished with ova, the remaining six sup-

porting spermaria. The oral extremity of each polype can be inverted for protection into the summit of its calcareous tube, but it is wrong to suppose that the latter completely invests the soft parts of the animal, the corallum of *Tubipora* being a true tissue secretion. Its horizontal outer plates are suggestive of a distinct analogy to the

FIG. 12.

TUBIPORA MUSICA.

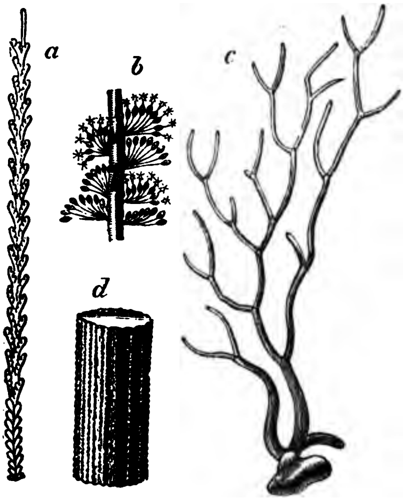
(*Fragment of corallum, of the natural size.*)

Tabulata, nor are traces of internal tabulæ wholly wanting. The characteristic form of *Tubipora* seems due to the periodic budding of polypes from the distal surface of the plates, while at the same time certain of the older corallites continue to increase in height. But neither the minute structure nor developement of this interesting genus have yet received proper attention.

The *Gorgonidæ* differ from all other *Alcyonaria*

in having an erect branching cœnosarc, firmly rooted by its expanded proximal extremity (Fig. 13, *c*). Those which possess a horny sclerobasis have been by many writers confounded with the

Fig. 13.



PENNATULIDÆ AND GORGONIDÆ.

a, Dried stem of *Virgularia mirabilis*.
b, Portion of another stem, in the living condition.
c, Corallum of *Mopsea costata*.
d, Fragment of the same.
(*a* Is reduced one-third; *b* and *c* are of the natural size; *d* is magnified.)

Antipathidæ; but, apart from the anatomical features of their polypes, they may at once be known from the latter by the more or less sulcate aspect presented by the surface of the sclerobasis.

The Alcyonaria, as a group, seem destitute of locomotive power, though one family of this order, the *Pennatulidæ*, have been often regarded as oceanic, and described by such names as "swimming polypes." It is more probable, however, that, under ordinary circumstances, these creatures live with their proximal extremity plunged firmly into the sand or mud of the sea-bottom; the distal end of the cœnosarc, which bears the numerous polypes, freely exposing itself to the influence of the clearer water above.

The cœnosarc of the *Pennatulidæ* may be slender and simply elongate, with very short pinnules, or lateral lobes, bearing the polypes, as in *Virgularia*, the sclerobasis of which is rigid, tapering towards its extremities, and densely calcareous (Fig. 13, *a*). In the true Sea-pens, forming the genus *Pennatula* and its near allies, the pinnules are very conspicuous, and so modified as to arrangement and comparative size that the whole mass presents a striking resemblance to a bird's feather. The proximal end of the cœnosarc, often for nearly half its length, is bare of pinnules or polypes, appearing swollen and fleshy. In other *Pennatulidæ* the entire cœnosarc is club-shaped, without any pinnules, the polypes being irregularly scattered.

Four families of Alcyonaria may be defined :—

Order Alcyonaria.

Family 1. Alcyonidæ.

Corallum sclerodermic, in general spicular, without true calcareous thecæ. *Cœnosarc* fixed.

Family 2. Tubiporidæ.

Corallum consisting of a number of distinct corallites, destitute of septa, their thecæ united externally by horizontal plates, arranged at distant intervals. *Cœnosarc* fixed.

Family 3. PENNATULIDÆ.
Corallum sclerobasic, tissue secretions also being sometimes present. *Cœnosarc* free.

Family 4. GORGONIDÆ.
Corallum sclerobasic, sulcate, with or without additional tissue secretions. *Cœnosarc* shrub-like, attached by its expanded proximal extremity.

In concluding this Lecture, I have to direct your attention to the Crustacea, that important group of the Subkingdom Entomozoa, which has given the name of Malacozoic, or age of Crustaceans and Mollusks, to the Silurian period of the earth's history.

The Subkingdom, called Entomozoa, or Articulata, of Cuvier, is thus divided:—

SUBKINGDOM ENTOMOZOA.

SUBDIVISIONS.	*Classes.*
I. ARTHROPODS, ... (τὰ τοὺς πόδας ἀρθρωδεῖς ἔχοντα),	1. Insects. 2. Myriapods. 3. Arachnids. 4. Crustaceans.
II. WORMS, ...	5. Annulata. 6. Entozoa. 7. Rotatoria.

Of the seven classes into which the Entomozoa are divided, the last two, Entozoa and Rotatoria, are entirely unknown in the fossil condition; and the second and third, Myriapods and Arachnids, are so rare that all mention of them may be omitted in a manual.

There remain for consideration the Insects, the Annulates, and the Crustaceans.

The Insects and Crustaceans are possessed of limbs, and in this respect differ essentially from the Annulates, or ringed Worms.

The Insects, partly on account of their fragile structure, and partly on account of their terrestrial

habits, and the Annulates, on account of their soft bodies, are rare in the fossil state, as compared with the Crustaceans, which were well fitted, by their calcareous shells and marine life for preservation in geological deposits. The first discovery of fossil insects in the older rocks was made in the iron stone nodules of Coalbrookdale collieries, and consisted of wings of Neuroptera and elytra of Coleoptera. Similar remains were afterwards discovered in the Carboniferous deposits of Saarbrücke and other localities. In the Lias deposits of Gloucestershire, and in the Stonesfield slate belonging to the great Oolite, the remains of Insects have been long known. The upper Jurassic deposits, and the lithographic limestone of Solenhofen in particular, abound with remains of insect life, preserved with the perfection characteristic of all the lithographic fossils.

In the tertiary deposits, the exuviæ of insects become so abundant, that they are capable of giving much information as to the climate and other conditions under which the insects lived; and some of these fossils, such as those preserved in amber, are as perfect and as easily studied as the specimens in an entomological museum.

The Annulates, or ringed Worms, are well known to the geologist, in all deposits, from the burrows and tracks they have left in the mud or sand, subsequently consolidated into rock; but they scarcely deserve more than a passing notice, as their anatomy and structure are quite unknown, and cannot be recorded in the fossil remains of their burrows. There is also good reason for believing that many of our so-called worm-tracks were made by Crustaceans, Mollusks, and other animals that burrow

and walk upon the wet sand and mud that usually border the edge of every sea and lake.

The Class Crustacea is divided into the following Orders and Families :—

CLASS CRUSTACEA.

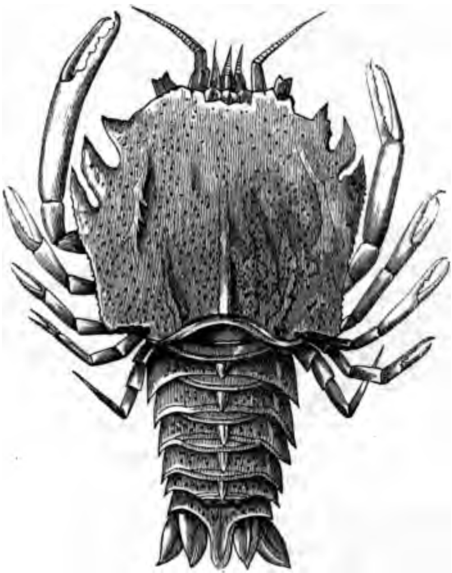
ORDERS.	
1. PODOPHTHALMS (ποδοφθαλμίαι).	Two compound eyes, placed on a binarticulate moveable petiole; carapace large, covering head, thorax, and anterior abdomen; gills covered by the sides of shield; feet, 5–6 pairs.
2. STOMAPODS (τὰ ζῶα τὸ στόμα μεταξὺ τῶν ποδῶν ἔχοντα).	Two compound eyes, placed on a binarticulate moveable petiole; feet 6–8 pairs; gills adhering to the caudal or thoracic feet, uncovered; shell thin or membranous.
3. HEDRIOPHTHALMS (ἑδριοφθαλμίαι).	Head distinct from thorax, without a common carapace; thoracic rings provided with feet; no true gills, but respiration is partly effected by means of the appendages; eyes sessile.
4. BRANCHIOPODS (τὰ ζῶα τὰ βράγχια ἐπὶ τοῖς ποσὶν ἔχοντα).	Feet lamellar, forming membranous leaves, which serve for respiration; two compound eyes.
5. COPEPODS (τὰ ζῶα τοὺς πόδας κοπωδεῖς ἔχοντα).	Feet natatory, often cloven into two oars; abdominal appendages undeveloped; eyes sessile.
6. OSTRACODS (ὀστρακωδῆ).	Provided with a bivalved carapace, oval or reniform.
7. CIRRIPEDES (Cirratis pedibus).	Fixed when adult; enclosed in a multivalve shell; provided with two multarticulate cirri.

Orders.	
8. Xiphurids (τὰ ζῶα τὰς ὀυρὰς ξιφωδεῖς ἔχοντα).	Caudal extremity prolonged into a sword-like spike; mastication effected by the coxæ of the feet.
9. Trilobites (τὰ ζῶα τρεῖς λόβους ἔχοντα).	Of an oval form; composed of segments divided into three lobes by two lateral depressions; the first segment, which is also the largest, carries the eyes.
10. Eurypterids (τὰ ζῶα τὰς εὐρείας πτέριδας ἔχοντα).	Thoracico-abdominal segments free; anterior segments united into a shield bearing a pair of marginal or subcentral eyes; three or four pairs of cephalic appendages, the posterior of which form swimming feet; integuments sculptured.

I. Podophthalms.—The Podophthalms, or Decapod Crustaceans, comprise all those known as crabs, lobsters, shrimps, &c., and are characterized by true gills, attached to the sides of the body, and enclosed in a gill cavity; their head is united to the thorax, and protected by a carapace extending to the abdomen; they have moveable stalked eyes, and generally five pairs of walking or prehensile feet.

They are usually subdivided into three groups, characterized as long-tailed, short-tailed, and tailless. The long-tailed Decapods, *Decapoda macroura* (lobsters and shrimps), abounded during the early part of the Neozoic period, and their remains are frequently found in the Oolitic rocks. One of the most typical forms of this period is the *Eryon arctiformis*, represented in Fig. 14, and is found frequently in the lithographic limestone of Solenhofen.

FIG. 14.



ERYON ARCTIFORMIS.

(Lithographic limestone, Solenhofen.)

II. Stomapods.—These Crustaceans are almost unknown in the fossil condition, and are represented by one or two Squills found in the Oolite of Solenhofen, and in the tertiary beds of Monte Bolca.

III. Hedriophthalms.—The Hedriophthalms, or Sessile-eyed Crustaceans, though largely represented in existing nature, by both terrestrial and marine forms, occur only sparingly in the fossil condition. Some naturalists are inclined to refer the Trilobites to this order of Crustaceans, while others consider

that they find a more suitable position in the next order of Branchiopods.

The Hedriophthalms are usually divided into Læmodipods, Amphipods, and Isopods, to which latter family the woodlice belong. I have selected the *Oniscus entomon* of the Baltic as a typical species of Hedriophthalm.

Fig. 15.

SEA LOUSE OF THE BALTIC.
(*Oniscus entomon.*)

It is found in abundance in the Baltic Sea, at depths varying from eighteen to forty fathoms, wherever the sea bottom is composed of decayed wood, which furnishes food to the smaller Crustaceans on which the Oniscus feeds. The Trilobites were, in all probability, social in their habits, like these Crustaceans, and appear to have been somewhat allied to them in anatomical structure.

IV. Branchiopods.—Many naturalists of the highest eminence, including Pictet and Van der Hoeven, place the Trilobites among the Branchiopod Crustaceans; considering their resemblances to the Isopods to be merely resemblances of analogy. We believe, however, that it is more convenient for the geologist to describe the Trilobites as a distinct order of

Crustaceans; and if on further discoveries respecting the structure of their feet, it should be found that they are Branchiopods, it is easy to replace them in this order. If the Trilobites be excluded, there remain only a few species of Apus and Dithyrocaris as fossil representatives of the Branchiopod Crustaceans.

V. Copepods.—These Crustaceans are divisible into two groups, according as they possess mouths adapted to suction (Fish-lice), or to mastication. They are now generally supposed not to occur in the fossil condition, as the remarkable fossils known under the name of Eurypterids are now formed into a distinct order. The Eurypterids resemble the Copepods in their sessile eyes, natatory feet, and membranous shell; but they differ from them in so many important particulars, that by common consent they have been removed into a distinct order, which is absolutely unknown in the living creation.

VI. Ostracods.—This order of Crustaceans contains the Cytheræ, Cyprides, and Cypridinæ, minute bivalved Crustaceans, which have been found in deposits of every age of the globe. They are characterized by a bivalved carapace, oval or kidney-shaped, provided with a dorsal hinge, and are generally minute, sometimes even microscopic. Many of these minute Crustaceans are undistinguishable from living forms. In the lower part of the Upper Palæozoic system, in rocks of slaty texture, found abundantly in Devonshire, and on the Rhine, they are so numerous as to give a name to the rock in which they occur, and which is called the Cypridina-schiefer. This rock is supposed to be characteristic of the Devonian period; and the *singular appearance* of the minute Cypridinæ, dot-

ting the smooth surface of the fine-grained slate, is not easily forgotten, when once it has been well seen in the field.

VII. Cirripedes.—These Crustaceans occur but rarely in the fossil state, and only in very recent deposits. They are interesting to the geologist, principally on account of the remarkable fossil, *Aptychus*, from the Solenhofen limestone, which is regarded by some naturalists as a Cirripede Crustacean, and by others as the operculum of the Ammonite, or as the internal cast of its stomach; this singular fossil has also been supposed to be a bivalve shell, like Tellina, to be the palatal tooth of a fish, and also the internal bone of a squid. The numerous theories as to the nature of this fossil are instructive, as showing the inherent difficulties of Palæontology, and the ingenuity of geologists.

VIII. Xiphurids.—The King Crabs are distinguished easily from all other Crustaceans by their structure. Their body is composed of three parts: a cephalothoracic buckler, carrying two pairs of eyes, one simple and the other compound; an abdomen of the form of an inequilateral indented hexagon; and a long sword-like tail, from which the order derives its name. Their mouth is placed very far back, and mastication is effected by the bases of the five feet, which are roughened for the purpose; in front of the mouth are placed a small pair of antennæ, furnished with prehensile pincers, and it is terminated behind by two bristly processes attached to the first abdominal segment, on the back of which the large oviducts open; respiration is effected by means of gills, placed on the last five abdominal segments.

The best known fossil species are the Belinurus and Limulus of the Carboniferous and Jurassic

periods, respectively. It is worthy of remark that all the fossil forms of Xiphurids are very small, when compared with the great King Crabs of the Moluccas and of North America.

IX. Trilobites.—These remarkable Crustaceans are known only in the fossil state, and existed in the Malacozoic epoch only. They abound in the Silurian rocks, of all ages, and are as characteristic of these rocks as are the Graptolites. One or two species only, such as Phillipsia and Griffithides, are found in the Carboniferous rocks; but at the close of the Palæozoic period they disappeared for ever from the surface of the globe.

The accompanying Fig. 16, which represents a fine Trilobite of the Trenton limestone in New York, will serve to illustrate the general structure of these Crustaceans. Its anterior extremity is formed of the *Head*, *Buckler*, *Cephalothorax*, or *Scutum capitale*, divided into three distinct plates, at the flexures of the sutures of which two large compound eyes are placed. The central plate is called the *glabellum*, and the lateral plates are called *jaws*. The central portion is formed *of eight segments* (of

Fig. 16.

ISOTELUS GIGAS.

which only seven are visible in the figure, one having been pushed, after disarticulation, under the buckler), which are moveable upon each other and upon the buckler, like the rings of a lobster's tail. This portion of the Trilobite is called the *Trunk*, *Thorax*, or *Abdomen*. The posterior portion of the body is formed of eight segments, soldered together into one piece, called the *Tail*, *Post-abdomen*, *Pygidium*, or *Scutum caudale*.

Each of these portions of the body is divided into three lobes by two longitudinal depressions, which are only faintly marked in the genus Isotelus, but which are prominent in most genera of the Trilobites, and to which their name is due.

Many, if not all, of the Trilobites were capable of rolling themselves up into a ball, like Woodlice, and, to facilitate this process, it is found that in many of them the contour of the head and tail is so constructed, that they fit accurately when rolled up. This is well shown in Fig. 17, representing *Phacops latifrons*, which abounds both in the rolled and unrolled condition in some of the Devonian rocks of the Eifel.

FIG. 17.

PHACOPS LATIFRONS.

The mouth was placed on the under side of the body, below the *glabellum*, and was provided with two plates, named the *hypostome* and *epistome*; the hypostome was placed in front of the mouth, like the *labrum* of the Branchiopods, and the *epistome* was placed inside, and parallel to the *hypostome*.

The following are the Families and Genera of the *Order of* Trilobites recognised by Pictet:—

Families.	Genera.
I. Harpidæ, ...	1. *Harpes.*
II. Paradoxidæ, ...	2. *Remopleurides.*
	3. *Paradoxides.*
	4. *Hydrocephalus*
	5. *Sao.*
	6. *Arionellus.*
	7. *Ellipsocephalus.*
	8. *Olenus.*
	9. *Peltura.*
	10. *Triarthrus.*
	11. *Conocephalus.*
III. Calymenidæ, ...	12. *Proetus.*
	13. *Phillipsia.*
	14. *Cyphaspis.*
	15. *Arethusina.*
	16. *Harpides.*
	17. *Phacops.*
	18. *Dalmannia.*
	19. *Calymene.*
	20. *Homalonotus.*
IV. Lichasidæ, ...	21. *Lichas.*
V. Trinuclidæ, ...	22. *Trinucleus.*
	23. *Ampyx.*
	24. *Dionide.*
VI. Asaphidæ, ...	25. *Asaphus.*
	26. *Symphysurus*
	27. *Ogygia.*
VII. Æglinidæ, ...	28. *Æglina.*
VIII. Illænidæ, ...	29. *Illænus.*
	30. *Nileus.*
IX. Odontopleuridæ, . .	31. *Acidaspis.*
	32. *Cheirurus.*
	33. *Placoparia.*
	34. *Sphærexochus.*
	35. *Staurocephalus.*
	36. *Deiphon.*
	37. *Zethus.*
	38. *Dindymene.*
X. Amphionidæ, ...	39. *Amphion.*
	40. *Cromus.*
	41. *Encrinurus.*
XI. Brontidæ, ...	42. *Bronteus.*
XII. Agnostidæ, ...	43. *Agnostus.*

The preceding families may be readily determined by means of the following key, or scheme, which will be found useful by the young palæontologist:—

TRILOBITA.

1.	Head very unlike tail, ...	2
	Head like tail, trunk small,	Family 1. Agnostidæ.
2.	Ribs furrowed, or flat, ...	3
	Ribs ridged, ...	10
3.	More than twenty segments in trunk, ...	Family 2. Harpidæ.
	Less than twenty segments in trunk, ...	4
4.	Border of head perforated,	Family 3. Trinucleidæ.
	Border of head not perforated, ...	5
5.	Tail small, trunk large, .	Family 4. Paradoxidæ.
	Tail and trunk of average size, ...	6
6.	Trunk of eight segments, or more, ...	7
	Trunk of less than eight segments, ...	Family 5. Æglinidæ.
7.	Trunk of 11–18 segments, ...	8
	Trunk of 8–10 segments, ...	9
8.	Tail small, head smaller than trunk, ...	Family 6. Calymenidæ.
	Tail broad, ...	Family 7. Lichasidæ.
9.	Tail smooth, of few segments, ...	Family 8. Illænidæ.
	Tail of many and distinct segments, ...	Family 9. Asaphidæ.
10.	Tail terminated by spines, ...	11
	Tail without spines, semicircular, furrowed by radial grooves, ...	Family 10. Brontidæ.
11.	Less than five segments in tail, ...	Family 11. Odontopleuridæ.
	More than five segments in tail, ...	Family 12. Amphionidæ.

X. Eurypterids.—These remarkable Crustaceans were formerly classed with the Copepods, but are now universally regarded as a distinct fossil order. Their general form and appearance are shown in the Fig. 18, which represents a restored specimen in the Museum of Trinity College.

FIG. 18.

PTERYGOTUS ACUMINATUS.
(Lesmahago, Lanarkshire.)

They vary from ten or twelve inches in length, up to five or six feet, and are found in the Upper Silurian and Lower Devonian rocks.

One of the most remarkable characteristics of the Eurypterids is the conversion of one pair of the antennæ into prehensile organs, a peculiarity which shows their position among the Crustaceans to have been an inferior one, as it indicates the degradation of an organ of sense to a simply mechanical use.

In concluding this Lecture, it will be useful to examine the results deducible from the history of

the Protozoa, Cœlenterozoa, and Entomozoa, as to the progress and succession of organic forms upon the globe.

The two following laws appear traceable, and we shall find them further confirmed by the history of the other classes of the Animal and Vegetable Kingdoms.

Law I. *The Palæozoic forms of life differed widely in type from the Neozoic forms.*

Law II. *The Neozoic forms of life belong generally to higher types than the Palæozoic forms.*

The first of these laws is illustrated among the Cœlenterozoa by the prevalence of the Rugose and Tabulate corals in the Palæozoic rocks, and by the Perforate and Imperforate corals in the Neozoic rocks; we thus see two totally distinct types of corals in the two series of rocks. The first law is equally well marked in the Entomozoa, by the prevalence of the Trilobites and Eurypterids in the Palæozoic rocks, which orders disappear completely in the Neozoic rocks, where they are replaced by the Podophthalms and other forms of Crustaceans more closely resembling those now prevalent. The second law, so far as relates to the three classes of animals under consideration, is founded on the history of the Crustaceans only; for we have no reason for believing that the sponges and corals of the Palæozoic period were inferior in organization to those of the Neozoic epoch. The history of the Crustaceans, however, indicates improvement of type, most unmistakeably. These animals may be divided, with Cuvier, into the Malacostracous and Entomostracous,—the first including the first three of the orders adopted by us in p. 201, and the latter *containing* the remaining seven. The Malacostraca

are superior to the Entomostraca in many respects; for example, they contain all the Crustaceans provided with moveable eyes; and they have a much larger number of segments devoted to the special senses, and less to merely mechanical uses:—thus in the Decapods, the first segment is devoted to sight; the second and third, to the antennæ (touch); from the fourth to the ninth, to the mouth; from the tenth to the fourteenth, to prehension and locomotion; and from the fifteenth to the twenty-first belong to the abdomen.

In the Xiphurids, on the contrary, the antennæ are reduced to a small pair of pincer legs, all the mouth organs are true locomotive legs, and the abdomen is reduced to a straight simple spine.

The Trilobites and Eurypterids, which were the prevailing Crustaceans of the Palæozoic period, to the exclusion of the Podophthalms, belong to the lower groups of the class, in which the segments are not appropriated so completely as in the higher groups to the organs of sense, and the uses of the head. We are entitled, therefore, to conclude, that the Malacozoic, or Lower Silurian period, owes its title of Crustacean Age rather to the number and size of its Crustaceans, than to their high organization, and that they must be regarded as inferior to the types of Crustacean life that appeared in the Neozoic period, and which still inhabit our seas.

Those who regard the Trilobites and Eurypterids as the ancestors of the Lobsters, Crabs, and Shrimps, would say that the Crustaceans progressed as the world grew older; while geologists who prefer positive science to speculation, are content simply to state as an ultimate fact, that the Neozoic Crustaceans were superior in organization to the *Palæozoic.*

LECTURE IX.

ZOOLOGICAL CURVE OF FISHES—CLASSIFICATION OF FISHES —FOSSIL FISHES—CARTILAGINOUS FISHES—GANOIDS— CHORDA DORSALIS.

WE have to-day to consider the history of fossil Fishes. These constitute so important a class, that they have given a name to one of the great periods in the history of the globe. Dividing geological epochs into four periods, namely, the Eozoic, the Lower and Upper Palæozoic, and the Neozoic, which are probably of equal value in point of time, the second of these, or Lower Palæozoic, is called Malacozoic, or Age of Crustaceans, from the preponderance of Crustaceans during it; and the third is called Ichthyozoic, or Age of Fishes. It commences with the upper part of the Silurian system, and base of the Old Red Sandstone. Shortly after the first appearance of the fossil Fishes, in conformity with the law that I have already explained, they appear to have rapidly reached a maximum of developement both as to numbers and bulk; and when they had reached that maximum of developement, then, according to the law of decadence which has been observed in other fossils also, they declined in numbers. This is well shown in Diagram No. II., p. 104, representing the *zoological* importance of Fishes. They rise rapidly

in the commencement of the Upper Palæozoic period to 21 per cent. of the whole fossil population of the globe; so that, as far as fossils give us evidence, of every five creatures, living on the globe during this period, one was a Fish. This, you will observe, gives a degree of importance to the Fishes of the Ichthyozoic period quite comparable to that attained by the Crustaceans during the reign of the Trilobites and Eurypterids in the Lower Palæozoic period. Having reached that degree of importance in the time corresponding with the Old Red Sandstone and Devonian period, they fall off; then they made a rally at the commencement of the Neozoic period, and fell off again.

We have defined the zoological importance of a group of fossils to be the percentage which the number of its species bears to the total number of species in the coexisting population of the globe. But this, I need hardly say, is not the measure of the real importance of any group of animals. Man himself, who is unquestionably the most important animal on the globe at present, is in a minority of one. He would not appear upon such a diagram as that in p. 104, as having any degree of zoological importance at all. It is therefore plain that we must distinguish between the degree of perfection of the animal and its importance in point of mere numbers. A smaller and more intelligent race may govern a more numerous one; and it is by virtue of this power of governing that man himself holds his place.

The appearance of Fishes on the earth constitutes an important step in the history of life on the globe, because they are Vertebrate animals. We find traces of Protozoa in the oldest rocks, and they flou-

rish at the present day; we have had the Cœlenterozoa, as represented by the corals, and the Mollusks, or Malacozoa, from the very earliest period; and the Crustaceans also are represented from the very beginning, for Trilobites appear almost simultaneously with the first commencement of life on the globe.

It must be considered, therefore, that a new era took place in the life of the globe when the first vertebrate animal appeared on it; and the vertebrate animals that appeared first were the lowest in the scale of organization. The Reptiles appeared next; and the Mammals last; and if we consider the successive appearance of the Fishes, the Reptiles, the Mammals, and Man, we cannot deny the truth of what was asserted by Cuvier, that there has been a general progress in the developement of life upon the globe. It has been commonly said, in reply to this, that the Fishes themselves supply an argument in contradiction to it,—that, if you examine the history of this class of animals in detail, you will find that, although the whole class appeared on the surface of the globe somewhat in the order of their zoological dignity, yet they have not progressed from the simplest types and forms to the more complex. It is not at all necessary, however, that this should be the case, in order to establish the general theory of progress on the globe; there is but little evidence in favour of a theory of developement that supposes the successive races of fossils to have sprung by merely natural laws from their predecessors; but at the same time it cannot be denied that it has pleased the Creator to proceed, in the succession of creations on the globe, according to a certain method or law.

Fishes, as shown in Diagram No. II., p. 104, have retrograded in numerical importance. It is quite possible, however, that, though they have diminished in numbers, they may not have retrograded in point of organization. In order to examine this question, we must consider Fishes with regard to their classification; and, for the purposes of the geologist, no classification is of any value that does not bear an intimate reference to the hard parts of the Fish. Therefore the teeth, the spines, the skeleton, and the scales of the Fishes are the points on which we must mainly rely.

We shall adopt Müller's classification of Fishes, as it seems to combine attention to anatomical structure and to external persistent characters, in a greater degree than any other classification we are acquainted with.

FISHES.

SUBCLASS.	
I. LEPTOCARDIANS, . . (οἱ ἰχθῦς τὰς καρδίας λεπτὰς ἔχοντες),	Heart represented by a muscular vascular system; brain not distinct from spinal marrow.
II. CYCLOSTOMES, . . . (οἱ ἰχθῦς τὰ στόματα κυκλοειδῆ ἔχοντες),	Cartilaginous; jaws replaced by a cartilaginous ring; pectoral and ventral fins wanting.
III. SIRENOIDS, ... (οἱ ἰχθῦς σειρηνωδεῖς),	Possess both lungs and gills permanently.
IV. PLACOIDS, ... (οἱ ἰχθῦς τὰς λεπίδας πλακωδεῖς ἔχοντες),	Skin furnished with bony plates irregularly arranged, and terminating in points or hooks. Skeleton cartilaginous.
V. GANOIDS, ... (οἱ ἰχθῦς τὰς λεπίδας γανωδεῖς ἔχοντες),	Scales covered with enamel; fins provided with bony rays; often heterocercal; notochord persistent. Skeleton generally cartilaginous.
VI. TELEOSTEANS, . . . (οἱ ἰχθῦς τέλεια οστῆ ἔχοντες),	Skeleton bony.

These Subclasses of Fishes are represented in the fossil state, by the following Families:—

Subclass.	Fossil Families.
I. Leptocardians,	*None.*
II. Cyclostomes,	*None.*
III. Sirenoids,	*None.*
IV. Placoids,	1. *Chimæridæ.*
	2. *Squalidæ.*
	3. *Hybodontidæ.*
	4. *Cestracionidæ.*
	5. *Squatinidæ.*
	6. *Pristidæ.*
	7. *Rajidæ.*
	8. *Myliobatidæ.*
V. Ganoids,	9. *Amiadæ.*
	10. *Leptolepidæ.*
	11. *Cœlacanthidæ.*
	12. *Holoptychidæ.*
	13. *Polypteridæ.*
	14. *Lepidosteidæ.*
	15. *Acanthodidæ.*
	16. *Dipteridæ.*
	17. *Pycnodontidæ.*
	18. *Cephalaspidæ.*
	19. *Sturionidæ.*
	Orders.
VI. Teleosteans,	*Ctenoids.*
	Pleuronectoids.
	Cycloids.

Three of the Subclasses may be excluded from our consideration, because with them as geologists we have nothing to do; and indeed, even in the living creation, some of them are of more importance from their classificatory value than from the number of animals that enter into them. The Sirenoids are Fishes that are provided during the whole of their existence with both lungs and gills, and form a very restricted class, but one of high interest. They include the celebrated Lepidosiren, or Mudfish, of the African rivers. The Cyclostomes,

or round-mouthed Fishes, include the lampreys; they are not known in a fossil condition. The Leptocardians are so called from possessing a muscular arterial tube in place of a heart; and they are Fishes also which have no brain as distinguished from a spinal cord. The brain in the vertebrate animals is to be regarded as a portion of the spinal chord, which discharges special functions. In this low class of Fishes, the brain and the spinal chord do not appear to be distinguishable; and the functions of the brain, such as it is, are performed by the extremity of the spinal chord.

There remain for consideration the Teleosteans, or Fishes endowed with perfect bony skeletons; the Ganoids, or Fishes provided with scales covered with brilliant enamel; and the Placoids, or Fishes which are furnished with a skin covered with plates and tubercles of various kinds.

Agassiz divided Fishes into two groups, according as their scales were enamelled or not enamelled. Those with enamelled scales are divided into Placoids and Ganoids; and those having scales not enamelled into Ctenoids and Cycloids; and to these other naturalists have added a fifth order, the Pleuronectoids, which embraces the flat Fishes.

The first division among the Fishes that we have to deal with is that of the Fishes that have bony skeletons, and those that have only cartilaginous skeletons. Amongst the living Fishes we are much more familiar with those that have bony than those that have cartilaginous skeletons. The Placoid and Ganoid Fishes as a group are provided with cartilaginous, and not bony skeletons, although there are some Ganoids found fossil, which possess a perfect bony skeleton. Amongst the living Fishes,

with the exception of the ray, the sturgeon, the shark, and other Fishes allied to these, the great majority possess perfect bones forming their skeletons. These constitute the Teleosteans of Müller; and the first thing that we have to remark with regard to the history of fossil Fishes on the globe is, that none of the Teleosteans lived before the Neozoic period. The curves of zoological importance and developement, Diagrams Nos. II. and III., p. 104, which rise to a maximum, fall to a minimum, and rise again, owe their second maximum to the creation of the Teleostean Fishes.

It has been a subject of discussion among geologists whether the Teleostean Fishes of the Neozoic period were more or less perfect than the older races of Placoid and Ganoid Fishes of the Palæozoic seas. The principal argument urged in favour of the superiority of the Neozoic Fishes is that derived from the more perfect ossification of their skeleton, especially of the vertebral column. In the cartilaginous Fishes the centres of the vertebræ remain permanently cartilaginous, while in the osseous Fishes the vertebræ, though at first cartilaginous, become subsequently ossified. Hence it is inferred, that the cartilaginous Fishes, as they remain permanently in the embryological condition of the osseous Fishes, are essentially of an inferior type.

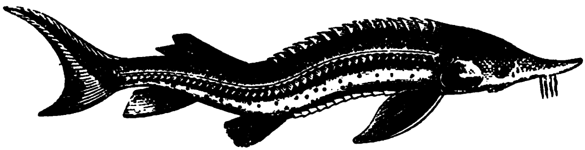
It seems to me that this argument is more plausible than solid; for it would follow, by the same kind of reasoning, that the young of many animals, which possess the power of locomotion, are essentially of an inferior type to the adults of the same animals, that are permanently fastened to the rocks on which they may chance to have once fixed themselves.

But, allowing the argument to have its full share of weight, the following facts in favour of the cartilaginous Fishes must not be neglected :—

1. They generally possess heterocercal or reptilian tails ; that is, the vertebral column, instead of terminating in a symmetrical caudal fin, is prolonged into the upper branch of that fin, giving a true reptilian character to the Fish.

This is well shown in the Fig. 19, which represents the Russian Sterlet, one of the sturgeon family, that abounds in almost all the inland branches of the great Russian rivers.

Fig. 19.



Russian Sterlet.

2. Several of the cartilaginous Fishes, as Aristotle had observed, are ovi-viviparous ; and in their mode of reproduction rather resemble birds and reptiles than ordinary Fish. In order to see the resemblance in the internal generative organs between the cartilaginous Fishes and the higher forms of organic life, it is only necessary for the anatomist to examine the ovaries, oviduct, and so-called uterus that secretes the egg shell in a pregnant ray, and compare them with the corresponding organs in any of our common birds. It would indeed scarcely be an exaggeration to say, that the generative organs of the female ray were those of a bird with a double ovary.

3. It must not be forgotten that the most de-

graded in type of all Fishes are to be found among the Teleosteans, viz., the Pleuronectoids, which swim permanently distorted to the right or left side, and are endowed with a hideous squint, that twists the two eyes to the upper side of the body, in order to counteract to some extent the disadvantages resulting from their distorted spine.

The foregoing facts must be carefully borne in mind in forming a conclusion as to the relative position of the Palæozoic and Neozoic Fishes.

If the skeleton alone were in question, I would readily admit that a bony skeleton is a better provision for a Fish than a cartilaginous skeleton; but we must remember that the Palæozoic Fishes that are contrasted with the Neozoic, although possessed of cartilaginous skeletons only, were yet provided with a dermoskeleton, or coat of mail, which was composed of true and genuine bone. This is well shown in Fig. 20, which represents the *Pterichthys Milleri*, one of the mail-clad Ganoids of the Old Red Sandstone of Scotland.

We may be allowed, on examining a Fish of this kind, to add another to the arguments already alleged in favour of the superiority of the cartilaginous Fishes.

Fishes are to be considered, like other vertebrates, as four-footed, the pectoral fins representing the fore, and the ventral fins the hind legs. In most Fishes, these fins seem placed in the animal only for the instruction of the anatomist, and to recall his attention to the type on which the vertebrates are constructed. In the Pterichthys, however, the pectoral fins are real arms, moved by powerful muscles, and bring to our recollection at once the type of some of the birds of powerful flight, such as the

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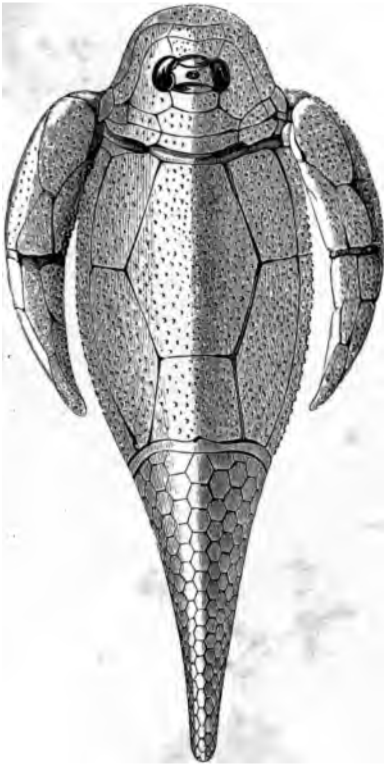
FIG. 20.



PTERICHTHYS MILLERI—RESTORED.
(Old Red Sandstone of Scotland.)

Gannet, in which the wings and their muscles constitute the most important part of the body, and to which all the other parts seem to be subordinate.

We may consider two classes of skeletons as capable of occurring in Fishes, namely, the endo-skeleton, which is the ordinary bony skeleton, and the exo-skeleton, which is a secretion of the skin. In the Ganoid Fishes, which are so called from the splendour of the enamelled scales with which they are covered, the protection given by these genuine bones was more complete than that which any Fish enjoys from its bony skeleton, because such a skeleton only affords an advantage over a cartilaginous skeleton by allowing a greater variety of points of attachment for the muscles of the Fish, and so admits of more powerful motions. But the Fishes of the ancient times, the Ganoid and Placoid, clothed in a defensive armour of true bone—some of it not only true bone, but true enamel (the outer portion of the scale being not merely bone, but enamel, like that which covers the teeth)—were more protected from enemies and injuries from without than any bony-skeletoned Fish could possibly be; and of course, being cased in so stiff an armour, it was not necessary for them to possess a bony skeleton as a point of attachment for their muscles. They were in some respects like an ancient knight in armour, or a modern iron-clad war ship—if better protected, somewhat more helpless.

It is now even known, that some of the Ganoid Fishes, which formerly were supposed to be altogether cartilaginous, had true bony skeletons; so that they must be regarded as in this respect similar in organization to the Neozoic Fishes.

So far as we know of the modern cartilaginous

Fishes—the sturgeon, the shark, the ray, and others,—we have no reason to believe them to be less intelligent, but, on the contrary, perhaps more intelligent than the osseous Fishes. They include amongst them the largest of all Fishes; and amongst these many are carnivorous. From its very definition, a carnivorous animal is probably more intelligent than a herbivorous animal. He has to feed upon a higher class of food,—a class endowed with higher faculties, and therefore better able to avoid his pursuit. The fact, therefore, of these great cartilaginous Fishes being carnivorous clearly shows, that they are not so low in the scale of creation as some of the advocates of mere system would make them.

The accompanying Fig. 21, which is drawn from a specimen in the Museum of Trinity College, represents the *Pycnodus platessus*, of the Tertiary beds of Monte Bolca, and is a good specimen of the Neozoic forms of the Ganoid Fishes. Its tail is homocercal, and its notochord permanent, although the processes from it which protected the spinal marrow and abdominal aorta are perfectly ossified; and at the same time, some of the dermal bony plates remain on the head. These Fishes were furnished principally with pavement teeth, shown in the figure, and lived on Crustaceans and shells, which were crushed by these teeth.

It is well worthy of remark, that the older Pycnodontidæ had heterocercal tails, and a completely cartilaginous skeleton, while the more modern forms possessed the anomalous anatomical structure just described.

In the vertebral column that gives a name to the Vertebrata, we have a succession of pieces which are jointed together, allowing a certain degree of

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FIG. 21.

PYCNODUS PLATESSUS.
(Tertiary beds of Monte Bolca.)

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FIG. 22.

HOLOPTYCHIUS ANDERSONI.
(Yellow Sandstone of Dura Den.)

motion between each of the joints, and so giving an elasticity and power of bending to a very considerable extent to the whole column. The vertebræ in the Fishes exhibit an hourglass cross section, like so many double concave lenses. The column of bodies of the vertebræ is called the notochord, or *Chorda piscium dorsalis*. This chorda dorsalis is divided into vertebræ, between which is placed a gelatinous substance, in masses shaped like double convex lenses, and which allows of a certain degree of motion. Along the back of the dorsal chord is placed the spinal marrow of the Fish; and along the ventral surface of the chorda dorsalis is placed the great abdominal aorta, the blood vessel which supplies the body. Now, in the Reptiles, in the dorsal chord we frequently find the bodies of the vertebræ, convex on one side, and concave on the other; so that, instead of their forming the shape of a double concave lens, they assume the shape of a meniscus. It is a remarkable fact that, in some of the older Reptiles, the double concave form of vertebra prevails, to the exclusion of the concavo-convex form, indicating an approach on the part of these Reptiles to the lower group of Fishes, which comes next below them in the scale of creation.

I shall conclude this Lecture, by giving two typical illustrations of the Palæozoic and Neozoic Fishes. For the Palæozoic type, I select the *Holoptychius Andersoni*, Fig. 22, found abundantly in the White Sandstone of Dura Den, in Fifeshire, which is of Lower Carboniferous age, and may be considered as the deposit that coincides with the maximum developement of Fishes in the Ichthyozoic period.

The Holoptychius is a Ganoid, and the type of the family Holoptychidæ, which possessed the fol-

lowing characters:—The rays of the fins hollow; skeleton cartilaginous; completely covered from the occiput to the tail with sculptured enamelled scales; large curved teeth, mixed with smaller ones; all the fins well developed, indicating active and voracious habits; eye placed over the mouth, giving a snake-like, reptilian character to the countenance. There can be no better type of the four footed Fish than the Holoptychius, whose pectoral and ventral fins were real arms and legs, capable of important uses; while the dorsal, anal, and caudal fins, on which the balancing and steering of the animal depend, are so developed as to lead to the conclusion that this mail-clad fish possessed swiftness and dexterity quite in keeping with the carnivorous tastes indicated by his teeth.

As a type of the Neozoic Fishes, I have chosen the *Semiophorus velicans*, Fig. 23, of the Tertiary Limestone of Monte Bolca. This Fish is a Ctenoid Teleostean, of the family Chætodontidæ, and is characterized by the enormous length of its dorsal and ventral fins, the rays of which are soft, with the exception of the anterior ones; the anal fin is small, and the pectorals seem to be altogether absent.

With respect to the Palæontological laws with which we concluded the preceding Lecture, it will be observed that the fossil Fishes establish the first law in as complete and satisfactory a manner as can be desired; but that they form a remarkable exception to the second law, as there can be little doubt that the Palæozoic Fishes approach the reptilian type more closely than the Neozoic Fishes; and that they are entitled, if on this account alone, to be regarded as possessing a higher organization.

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Fig. 23.

SEMEIOPHORUS VELICANS.
(Tertiary Limestone of Monte Bolca.)

LECTURE X.

PHYTOZOIC PERIOD — FOSSIL PLANTS — CONIFERS AND ACROGENS—CARBONIFEROUS PLANTS—SIGILLARIÆ AND LEPIDODENDRA—CALAMITES — FERNS—PALÆONTOLOGICAL LAWS.

WE have to-day to consider the history of Plants on the surface of the globe. The Upper Palæozoic period, which constitutes the third of the four great and almost equal periods into which we divide the history of the globe, might be as well denominated the Age of Plants as the Age of Fishes. Vegetation appears to have acquired a preponderance during this period that it certainly never had before, and probably has never acquired since. During this period, also, the forms of vegetable life assumed characters quite different from those with which we are acquainted in modern plants; and different also from those of the trees and plants which prevailed during the earlier parts of the Neozoic period. So difficult is the investigation of this subject, in consequence of the imperfect remains of Plants that are preserved, that it is with the greatest reluctance that professed botanists can be induced to express an opinion, or to direct their attention to the subject of fossil Plants. All the parts of the Plant on which natural, or even artificial systems of classification are founded, are hopelessly lost in the act of preserving it in the fossil

condition; and we have to add to this natural difficulty of studying fossil Plants the additional consideration, that the forms of Plants and the kind of vegetation with which we have to deal, in many respects differ so widely from those with which we are acquainted in the present creation, that all clue to the comparison of them appears to be lost. You will therefore understand that in no branch of palæontology have we more difficulties to contend with; and yet, at the same time, in no branch of this science have the results that have been obtained better rewarded the labours of the explorers.

As a general rule, there can be no question that the history of fossil vegetation on the surface of the globe leads to the conclusion, that there are but few fossil forms of vegetable life essentially different from those which we now find on various parts of the surface of the earth. This conclusion is identical with that which is so well known to have been established in the science of zoology. For, though the fossil forms are different, the proportions of animals different, and though many of them serve to fill up blanks in the zoological scale, none are irreconcileable with it, and few are to be found which do not fall easily into the scientific classifications of zoologists. The case is similar with respect to fossil Plants; but the strange fact presents itself in this Age of Plants, or Carboniferous period, that the Plants that are now very imperfect in their organization, and exceedingly minute in the scale on which they grow, were in these early times developed in such numbers, and on such a scale as to magnitude, as to equal the largest plants and trees of our more highly organized modern vegetation. We have to

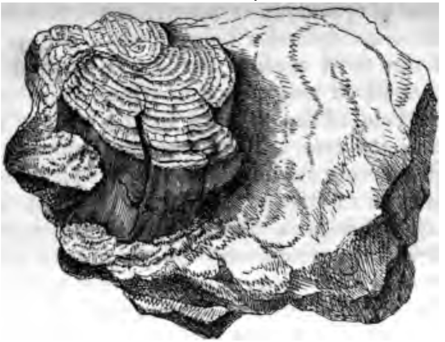
seek for the analogues of fossil Plants of the Carboniferous period amongst the humbler forms of the ferns, the clubmosses, and the grasses, rather than amongst the oaks, the chestnuts, and the palms of modern vegetation; and these clubmosses, ferns, and grasses of earlier times existed in the state of trees, many of them upwards of eighty feet high, and rivalling in their size and dimensions the more highly organized and perfect trees with which we are now familiar both in the temperate and in the tropical regions of the globe.

Amongst our modern trees, every person who has paid the slightest attention to the subject is acquainted with the fact that we have two great types, the Exogens and the Endogens; the Exogens, as their name implies, growing from without, in a series of cylinders, symmetrical round a central axis, the outer cylinder being always the newest; so that the cross section of the tree shows a number of annuli or rings, each of which represents a year or cycle of the seasons in the history of the growth of the tree. These are the common trees of the temperate regions. In the tropical regions another type of tree predominates; and these are called the Endogens. No annular arrangement can be observed in a cross section of one of these plants; but a number of woody bundles grow from below upwards with the growth of the plant, the newest and freshest of these woody bundles being in the centre; so that the tree throws out its leaves, as the palm does, from the top, growing from the newly-formed materials, or woody fibres at the centre. The consequence is, that the outer coat of such a tree as this becomes exceedingly hard. It is pressed continually by the growth from within;

and the woody portions near the outer circumference become denser and denser by the pressure which is exercised upon them from the central axis.

Although we have unmistakeable traces of Exogens in the earliest appearance of Plants upon the globe, in the period of the Carboniferous limestone, they certainly must have occupied a very small and unimportant place in the general vegetation of that time. The accompanying Fig. 24, illustrates a fragment of Exogenous wood, belonging to one of the Coniferæ, found in the lowest beds of the Carboniferous system in the north of the county of Mayo. It is probably as old a specimen of Exogenous wood as any yet found in Europe.

Fig. 24.



EXOGENOUS CONIFEROUS FOSSIL WOOD.
(From the Lower Carboniferous Limestone of Mayo.)

The fossil stems called Sternbergiæ are supposed to be casts of the pithy or open cellular interior of some Conifers.

As to the Endogens, we are not so certain of the

time when they commenced their appearance on the globe; but when we come to the Neozoic period, the later portion of the history of the earth, there can be no doubt that the Endogens existed in abundance as well as the Exogens. In fact, from the commencement of the Neozoic period to the present time, there appears to have been no lack of both these classes of Plants, although their first creation and appearance on the globe is to be dated from before the commencement of the Neozoic period.

The ferns and clubmosses, to which we refer the greater part of the fossil Plants, belonged to the third vegetable group, called Acrogens, which are unquestionably much lower in the scale of creation than either the Endogens or the Exogens. The Acrogens grew exclusively from the top, but not at all in so perfect a manner as the Endogens. They possess also, like the Endogens, central bundles of woody fibre.

In the extraordinary developement of Acrogens during the Carboniferous period, we find another instance of the law that inferior forms of life may, in the earlier periods of the earth's history, and shortly after their appearance on the globe, attain their maximum of developement both as to numbers and size, so as actually to acquire an importance numerically in the scale of creation to which their dignity, considered simply as more or less perfect plants or animals, does not entitle them. There can be no doubt that the gigantic clubmosses and ferns of the Coal period gave a character to the vegetation of the globe which even the densest forests of South America nowhere now present.

The geometrical law of symmetry to which these lower Plants are subject is more simple than the geometrical laws to which the higher classes of Plants conform themselves. The great majority of Acrogens develope their leaves in whorls, according to the simple law described in pp. 153, 4, and there illustrated by the example of the coal plant, *Sigillaria oculata;* but, as is well known, the developement of leaves in the majority of the Exogens takes place in a spiral manner, and is subjected to mathematical laws of a precise and complicated kind, especially in the *Coniferæ.*

Some time ago, having found from an examination of many fossil Plants that the law of the arrangement of their leaves was that of whorls, I consulted Professor Harvey as to the living Plants in which this curious and simple geometrical law of arrangement was to be found; and, on investigation, we came to the conclusion that it was a law very restricted in its application; and that the Exogens in particular to which this law of arrangement applied, and in which it was found, were amongst the lowest in point of organization of their class. The principal groups of Exogens in which this law was found to prevail were the *Ericaceæ* (heaths) and the *Casuarineæ*, which latter are confined to Australia, while the heaths are developed principally in South Africa; and both families are, in the opinion of many botanists, inferior in organization to the other groups of Exogens. It would therefore almost seem as if these Exogens,—the Ericaceæ of South Africa, and the Casuarineæ and Proteaceæ of Australia,—were the remains of older forms of Exogenous Plants which are dying out on the surface of the globe, and which retain, in their

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Fig. 25.

CYCLOSTIGMA.
(Carboniferous Slate, of Tallow Bridge.)

Fig. 26.

LEPIDODENDRUM MINUTUM AND CYCLOSTIGMA.
(Carboniferous Slate, of Tallow Bridge.)

obedience to this law of geometrical symmetry of the lower classes of Plants, a mark of their inferiority.

I have given in the Appendix to this Lecture, the details of my investigations on the whorled structure in Exogens.

The Plants of the Carboniferous period which are not exogenous are usually divided into the following Orders and Families :—

CARBONIFEROUS PLANTS.

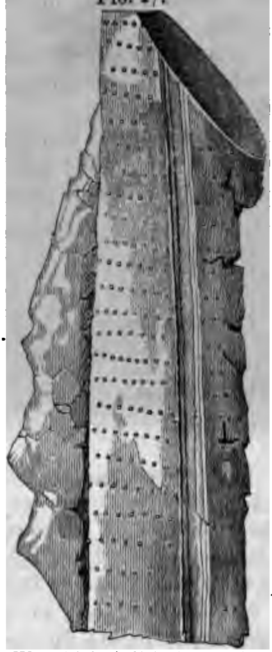
ORDERS.	*Families.*
I. SIGILLARIDS	1. *Cyclostigmaceæ.* 2. *Sigillariæ.* 3. *Stigmariæ.* 4. *Lepidodendra.*
II. CALAMITES	5. *Calamitaceæ.* 6. *Asterophyllaceæ.*
III. FERNS.	

I. Cyclostigmaceæ.—These Plants derive their name from the circular marks left in the bark by their leaf scars. They are characteristic of the Devonian period, and have been found in abundance in many localities in Ireland. In Figs. 25 and 26, I have represented, on a reduced scale, some specimens from Tallow Bridge, in the county of Waterford, and in Fig. 27, a fine specimen from Kiltorcan, in the county of Kilkenny, where these Plants are associated with fossil Ferns, Fishes, and Bivalve Mollusks, probably freshwater.

We know, as yet, but little of the structure of these remarkable fossils, although we have reason to believe that they possess close affinities to the Lepidodendra, and to the remarkable Plants called Knorriæ by the German palæontologists.

II. Sigillariæ.—These are so named, as may be seen from Figs. 28 and 29, from the seal-like impressions left by the leaf scars upon the stem of the plant. They exhibit in a remarkable manner the whorled arrangement of leaves characteristic of Acrogenous vegetation.

Fig. 27.



CYCLOSTIGMA KILTORKENSE.
Yellow Sandstone Beds.

The Sigillariæ are most abundant in the Lower Coal Measures, and seem to constitute the greater part of the substance of the coal; they are generally believed to have been marsh plants, while the Lepidodendra and Conifers occupied a higher and drier situation. Their stems grew as simple trunks to a height of from thirty feet to sixty feet without branches, and were covered with long narrow leaves, which left the scars from which the Plants have derived their name. These leaves, when found separately fossilized, have been called *Poacites*, *Cyperites*, &c.

III. Stigmariæ.—These Plants are now generally believed to be the roots of Sigillariæ and Lepidodendra, as they have been found in South Wales, *Lancashire*, and Nova Scotia, to lie in the under

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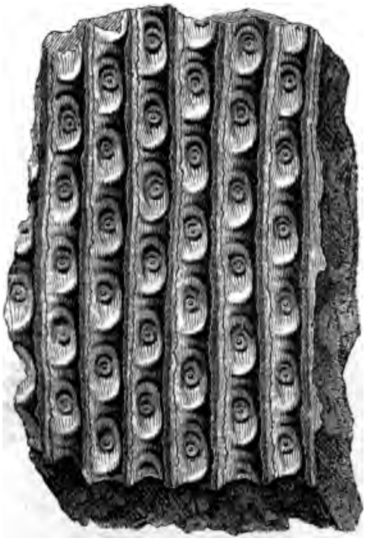
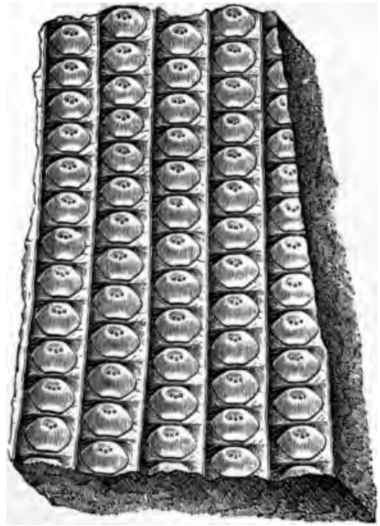
Fig. 28.



SIGILLARIA OCULATA.
(Coal Measures.)

Fig. 29.



SIGILLARIA TESSELLATA.
(Coal Measures.)

clay below the coal, and to form the roots of trees in the coal itself, which are either Sigillariæ or Lepidodendra; and few if any palæontologists now believe in the Stigmariæ as a distinct Family of fossil trees. The rounded impressions, generally depressed, which give a name to the group, are the traces of the rootlets that sprang from the central root stem, and resemble in their quincuncial geometrical arrangement the true leaf scars on the stem of the tree itself.

FIG. 30.

LEPIDODENDRON ELEGANS.
Coal Measures of Newcastle.

IV. Lepidodendra.—The general character of these remarkable trees is well shown in Fig. 30, which is

copied from a specimen of *Lepidodendron elegans*, figured by Lindley and Hutton, found in Newcastle. They were lofty woody trees, with leaf scars on both stem and branches, arranged in a quasi-quincuncial order, that, from its diagonal tendency

FIG. 31.

CALAMITES NODOSUS.
Coal Measures of Newcastle.

and apparent complication, recalls the arrangement of the leaves in the Conifers and modern Tree-ferns. Both in their foliation and fructification they resemble the Conifers, their leaves being sharp *woody* spikelets, and their fruit arranged in cones,

called Lepidostrobi, that resemble the cones of the pine tribe.

The Genus Halonia is closely allied to the Lepidodendra.

V. Calamitaceæ.—These fossil plants are characterized by their division into joints or segments, and by their fluted stems. Their general appearance is shown in Fig. 31, which represents the *Calamites nodosus*, from the Coal Measures of Newcastle. These Plants often grew to a height of twenty feet and upwards, and were associated with the Sigillariæ in the marshes, rather than with the Lepidodendra and Conifers. They appear to be closely allied to the following order, the Asterophyllaceæ; and both were, in all probability, the representatives in the Carboniferous period of the modern Equisetaceæ.

FIG. 32.

ASTEROPHYLLITES COMOSA.
Coal Measures of Newcastle.

VI. Asterophyllaceæ. — These were gigantic

Equisetaceæ, and are well represented in Fig. 32, which is taken from a specimen figured by Lindley and Hutton, from Newcastle. They are to be regarded as rather rare, as compared with other Carboniferous Fossil Plants.

VII. Ferns.—The fossil Ferns were mostly herbaceous, although a few Tree-ferns have been found. Their foliation and fructification so closely resemble those of recent ferns, that the most careless observer at once discovers their true modern affinities. I have chosen as illustrations, the *Pecopteris adiantoides*, and *Sphenopteris affinis*, Figs. 33 and 34, both of which are common forms in most of the coal deposits of Europe and America.

The general vegetation of the Coal period must be regarded as that of a swampy forest, in which gigantic forms of plants allied to the Lycopodiaceæ, Equisetaceæ, and Ferns, with a few Conifers, played the part of trees. When we consider what coal is —that it is fossil carbon, and composed of the wood of these trees; when we consider also that they possessed very little woody fibre as compared with the modern Exogens and Endogens, and that the greater part of their bulk must have been water and gases, which would escape in the fossilization of the tree; and examine the enormous thickness of coal that the carbon of these plants has formed in America, in Europe, and in Australia—we must come to the conclusion that the number and extent of these fossil forests must have exceeded anything that we have any conception of in modern times. I believe this extraordinary luxuriance of growth was intimately connected with the presence of a greater amount of carbonic acid

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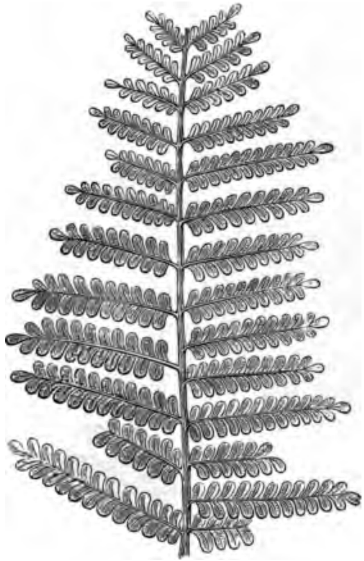
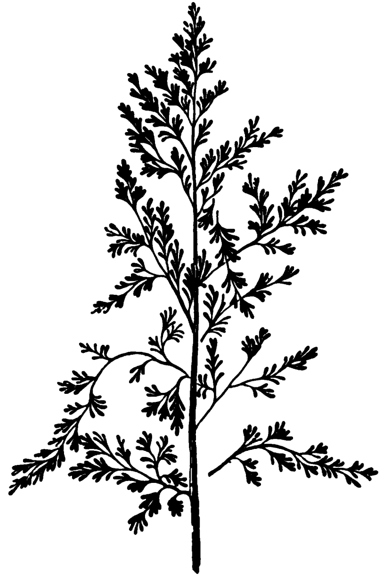
Fig. 33.



PECOPTERIS ADIANTOIDES.

Fig. 34.



SPHENOPTERIS AFFINIS.

in the atmosphere at the Carboniferous period than existed subsequently. There is good reason for believing that all the carbonic acid and carbon in the globe came originally from the atmosphere, whether it occurs in fossil plants, in limestone, or in magnesian carbonates. The presence of this large quantity of carbonic acid in the atmosphere would not have materially interfered with the developement or the comfort of the Crustaceans of the lower Palæozoic period, because they were, as a class, marine; whereas it would have assisted most powerfully in the production of those gigantic forests of the lower class of vegetables that flourished in the damp warm atmosphere that prevailed everywhere during the Coal period.

When we consider that the nearest analogues we can find in modern times to these fossil trees are little herbs, only a few inches in length, and that we have to infer from these the structure and arrangement of gigantic forest trees, you can readily understand the difficulties that impede the botanist in his attempts to make any examination of the fossil Flora. One of the great groups of Plants that prevailed, and constituted large trees during the upper Palæozoic period, was a group which is now represented by forms as low in the scale of creation, and as diminutive in size as the clubmosses—I mean the Equisetaceæ. The Equisetum, or horsetail, as it is commonly called, delights in the most damp and clayey banks, and luxuriates in heat and moisture like the clubmosses. But even if we take into account foreign specimens from tropical climates, we shall find this a very inferior group in the existing kingdom of Plants.

Before concluding this Lecture, I shall briefly

state the palæontological conclusions that may be drawn from the study of fossil Plants.

There are four distinctly marked deposits of carbon, resulting from vegetation, found in the strata of the earth.

1. Deposits of anthracite, and plumbago, found in many countries in the oldest stratified rocks; in Eastern Siberia and Greenland in gneissose granite; in Ireland, Scotland, and Russia, in thick beds in rocks of the Silurian age. These deposits have lost all trace of the original structure of the Plants from which they derive their origin, and belong evidently to periods of the most remote antiquity.

2. The coal beds proper of the newer Palæozoic epoch. This is frequently named the Ichthyozoic period, but might perhaps more appropriately be called the Phytozoic epoch.

3. The coal deposits of the Jurassic period, characterized principally by peculiar forms of Ferns, Conifers, and Cycads. These deposits occur in Sutherland, Yorkshire, Virginia, and probably in India.

4. Tertiary coal beds, formed principally of lignite, very imperfectly fossilized. The Brown coal of Germany, the Tertiary coal of Borneo, and other similar deposits, belong to this formation.

Long experience has shown that none of these coal deposits can be relied upon commercially, except the true Carboniferous or Palæozoic coal, which alone occurs in such quantities as to defray the cost and labour of really extensive mining operations. The reason of this fact must be sought in some peculiar combination of climatal and chemical conditions in the Carboniferous period, that

proved highly favourable to the developement of the remarkable growth of tree plants that constituted the vegetation of the earth at that time. These climatal and chemical conditions seem to have consisted principally in a much higher temperature, and a larger percentage of carbonic acid in the atmosphere.

The best proof that can be given of the high temperature of the Carboniferous period is to be found in the fact that beds of true Carboniferous coal (containing specimens of *Sphenopteris*, and associated with limestones and sandstones, including the following fossils—*Atrypa fallax*, *Producta sulcata*, *Spirifer Arcticus*, *Lithostrotion basaltiforme*, *Terebratula aspera*, *Atrypa primipilaris*, and others), are to be found in Banks's Land, Lat. 74° N., in Melville Island, Lat. 75° N., and in Byam Martin's and Bathurst Islands, Lat. 75°, 30′ N.

The temperature that would sustain a forest vegetation of gigantic Equisetaceæ, Tree-ferns, and Lycopodiaceæ in such a latitude, may well be supposed to have rendered the equatoreal regions of the globe uninhabitable by ordinary Plants and animals during the time in which the coal beds of the Arctic Archipelago were being deposited.

The palæontological Laws laid down in Lecture VIII. may be repeated with respect to fossil Plants; and an additional Law added, which we shall hereafter find to be only a particular case of a more general Law:—

Law I. *The Palæozoic forms of Plants differed widely in type from the Neozoic forms.*

Law II. *The Neozoic forms of Plants belong generally to higher types than the Palæozoic forms.*

Law III. *The inferior types of Palæozoic life were*

produced on a scale, gigantic as to magnitude, that is unknown among the Neozoic types.

The first two Laws require no illustration beyond what has been supplied in the former part of this Lecture; and in proof of the truth and generality of the third Law, I may instance the *Receptaculites Neptuni* among the palæozoic Foraminifers; the gigantic Pterygotus, attaining a length of eight feet, among the palæozoic Crustaceans; and the Ground Pines or Clubmosses (eighty feet high), and Equiseta (twenty feet high) of the palæozoic vegetation.

The third Palæontological Law that is thus shadowed forth from an examination of the palæozoic animals and plants may be more generally stated thus:—

Law III. *In each of the Subkingdoms of Nature, the earlier forms of life, though generally inferior in organization to the later forms, surpassed them in physical bulk.*

APPENDIX TO LECTURE X.

ON THE PHYLLOTAXIS OF WHORLS.

The extremely imperfect condition in which fossil plants are usually found, and the almost total absence of their more important organs, lead us naturally to lay stress on such characters as are found persistent in the fossil condition. Among these, one of the most important, as I believe, is the geometrical law of arrangement of their leaves. A careful examination of this arrangement leads me to conclude that the leaves of palæozoic fossil plants are arranged according to a different law from that which prevails in the ordinary exogens and endogens, and usually described in elementary text-books of botany.

The law of arrangement is very simple, and may be thus expressed:—

The leaves, or leaf scars, are arranged in whorls so placed, that each leaf is directly above or below a leaf of the alternate whorls, and intermediate to the leaves of the adjacent whorls.

The developement of leaves following this law may be easily conceived by imagining the whorl to ascend spirally on the stem, traversing an angle $\left(\frac{180^\circ}{n}\right)$ between each of its resting places, n denoting the number of leaves in each whorl. This is the same as supposing *each* leaf to have an independent law of developement of the ordinary kind, expressed by

$$\text{Divergence} = \frac{1}{2n}.$$

The leaves, according to this view, are developed in simultaneous whorls, and cannot be supposed to be produced in succession, as in alternate-leaved plants.

Some of the whorled-leaved exogens may be reduced to this law, such as the simple case of opposite-leaved plants, which is not reducible to the common law of Phyllotaxis, as we cannot suppose

the two opposite leaves to be produced in succession; but the great majority of exogens follow a different law.

According to all writers on botany, the leaves of alternate-leaved exogens and endogens are placed upon the stem, at angles represented by the fractions—

$$\tfrac{1}{2}, \tfrac{1}{3}, \tfrac{2}{5}, \tfrac{3}{8}, \tfrac{5}{13}, \tfrac{8}{21}, \tfrac{13}{34}, \text{\&c.},$$

of an entire circumference.

In opposite-leaved plants, which is the simplest case of whorled structure, we cannot assign any such law of developement to the leaves, even by calling to our aid the hypothesis of arrested growth; for the leaves succeed each other at intervals of $\frac{1}{2}$, $\frac{1}{4}$ alternately, and cannot be reduced to the phyllotaxis of alternate leaves. We should therefore, I believe, assign to all whorled plants a law of phyllotaxis of their own, which is very simple, and already stated.

The floral envelopes of almost all exogens and endogens follow this law of whorled structure, so much so that any deviation from it is remarked, and considered due to the suppression of a whorl, as in the case of the Primulaceæ. It is, therefore, evident that there must be some mode of passing from one law to the other, as both occur in the same plant. As it is impossible to reduce the law of alternate-leaved plants to that of the whorl-leaved plants, I have made some attempts in the opposite direction, but have not yet collected sufficient facts to draw any general conclusions. I shall give an example.

Many of the exogens possess a five-leaved whorled arrangement of their floral organs, while the leaves of the stem are arranged alternately at a divergence of $\frac{2}{5}$ths. This may be deduced from two whorls in the following manner:—If the whorls were converted into a spiral, they would consist of two spires, of five leaves each, discontinuous at an angle of $\frac{1}{10}$th; but if we suppose the alternate whorls and leaves suppressed, the two spirals would coalesce, and form one, taking two turns round the axis, and containing five leaves.

If I were at liberty to adopt the law of selection, I should say that, no doubt, the plant found it to its advantage to drop these supernumerary leaves, and so become elevated into the position of an alternate-leaved plant.

In the preceding case, in order to deduce the arrangement of the leaves from that of the flowers, we have supposed the suppression of alternate whorls, and of the alternate leaves of each whorl preserved, making a suppression of seventy-five per cent. of the leaves. In other cases, the suppression of leaves is only fifty per cent.—as in the case of most endogens, whose flowers consist of alternating whorls of three organs. If we suppose, in this case, the sup-

pression of alternate whorls, and a spiral arrangement, the divergence will become $\frac{1}{8}$.

In the case of opposite-leaved plants, the suppression of alternate whorls will give us the *distichous* arrangement, $\frac{1}{2}$; at an expenditure of fifty per cent. of leaves.

In these and many other cases we can deduce, by the hypothesis of suppression, the alternate-leaved phyllotaxis from the whorled; and it is worthy of remark, and leads me to my more immediate subject, that the whorled arrangement, which is rare (with the exception of opposite-leaved plants), among exogens and endogens, was the common arrangement of leaves among the coal-plants, and, so far as we know, among the plants of the Old Red Sandstone, which forms the base of the Carboniferous rocks.

The palæozoic trees and plants are referred to natural orders, resembling in many respects our recent Lycopodiaceæ, Equisetaceæ, and Ferns. In all these orders the whorled phyllotaxis of the kind I have described universally prevails.

I. *Lycopodiaceæ.*

1. *L. dendroideum.* (Herb. Oakes.) Canada.
   Leaves of stem arranged in alternate whorls of 7 leaves in each.
   Divergence = $\frac{1}{14}$

2. *L. densum.* New Zealand.
   Leaves of stem in alternate whorls of 7 each.
   Divergence = $\frac{1}{14}$

3. *L. clavatum.* Massachusetts.
   Leaves of stem and flower stalk in alternate whorls of 7 each.
   Divergence = $\frac{1}{14}$

4. *L. divaricatum.* Nepaul.
   Leaves of stem in alternate whorls of 11 each.
   Divergence = $\frac{1}{22}$

   Leaves of flower stalks in alternate whorls of 8 each.
   Divergence = $\frac{1}{16}$

5. *L.* (*n. sp.*) Caraccas, S. America.
   Leaves of lower stem in alternate whorls of 7 each.
   Divergence = $\frac{1}{14}$

   Leaves of upper stem in alternate whorls of 2 each. (i.e. opposite-leaved).
   Divergence = $\frac{1}{4}$

6. *L. volubile.* New Zealand.
Leaves of lower stem in alternate whorls of 4 each.
Divergence = $\frac{1}{8}$
Leaves of upper stem in alternate whorls of 2 each.
Divergence = $\frac{1}{4}$

7. *L. selago.* Canton Ticino.
Leaves of stem in alternate whorls of 4 each.
Divergence = $\frac{1}{8}$

8. *L. reflexum.* Pacific.
Leaves of stem in alternate whorls of 9 each.
Divergence = $\frac{1}{18}$

This plant has a striking external resemblance to *Lepidodendrum minutum*, and some of the smaller Cyclostigmas of Kiltorcan.

9. *L. quadrifasciatum.*
Leaves of stem in alternate whorls of 2 each.
Divergence = $\frac{1}{4}$

10. *L. verticillatum.* Mauritius.
Leaves of stem in alternate whorls of 7 each.
Divergence = $\frac{1}{14}$

This plant resembles some of the Kiltorcan plants, which have been called *Knorria.*

11. *L. gridoides.* Mauritius.
Leaves of stem in alternate whorls of 2 each.
Divergence = $\frac{1}{4}$

12. *L. flagellaria.* New Zealand, North Island.
Leaves of stem in alternate whorls of 2 each.
Divergence = $\frac{1}{4}$

13. *L. varium.* Lord Auckland's Islands.
Leaves of stem in alternate whorls of 4 each.
Divergence = $\frac{1}{8}$

14. *L. catharticum.* Peru.
Leaves of stem in alternate whorls of 2 each.
Divergence = $\frac{1}{4}$

15. *L.* (*n. sp.*). Quito.
Leaves of stem in alternate whorls of 8 each.
Divergence = $\frac{1}{16}$

This plant bears a close external resemblance, on a small scale, to *Lepidodendron dichotoma.*

Sufficient evidence has been adduced to prove that the Lycopodiaceæ follow the geometrical law of alternate whorls. Col-

lecting together the results, we find the following angles of divergence:—

In 6 species	an angle of	$\frac{1}{4}$
„ 5	„	$\frac{1}{14}$
„ 3	„	$\frac{1}{8}$
„ 2	„	$\frac{1}{16}$
„ 1	„	$\frac{1}{18}$
„ 1	„	$\frac{1}{22}$

These numbers correspond with whorls consisting of

2, 4, 8

leaves; being powers of 2; and whorls containing prime numbers of leaves

7, 9, 11.

The *prime* whorls could not give rise to any of the known Phyllotaxes of alternate-leaved plants; but the whorls of powers of 2 may do so as follows:—

(1.) The whorl of 2, by suppression of the alternate whorls, gives the phyllotaxis = $\frac{1}{2}$.

Reduction of 50 per cent. of leaves.

(2.) The whorl of 4, by suppression of the alternate whorls and alternate leaves, gives the phyllotaxis = $\frac{1}{2}$.

Reduction of 75 per cent. of leaves.

(3.) The whorl of 8 leaves, by suppression of the alternate whorls and of $\frac{2}{3}$rds of the remaining leaves, might give rise to the well-known phyllotaxis = $\frac{3}{8}$.

Reduction of 83 per cent. of leaves.

It may be supposed by some that the plants, having got rid of superfluous leaves, expended the surplus vitality thus acquired in perfecting their flowers and fruit into higher types; but if this be so, how are we to account for the retention of the whorled structure in the floral organs?

The calyx, corolla, and stamens of Exogens and Endogens obey the law of alternate whorls, when definite; but the pistil in many cases progresses into the spiral type. When the carpels are few and definite, they form a whorl; but when indefinite, as in *Ranunculus*, *Myosurus*, and *Magnolia*, and such like cases, they are as strictly spiral as leaves. Also in monstrous roses, we have the pistils returning to the condition of leaves, green, cut, and spirally arranged.

II. *Equisetaceæ.*

1. *Equisetum alpestre.* Norway (North) :—

Sheath whorls, alternate, . . .	4 in each.
Branch whorls, ...	7 ,,

2. *E.* (*sp.*) Ceylon :—

Sheath whorls, alternate, . . .	16 ,
Branch whorls (irregular), . . .	1 ,,
Fruit whorls, 10–13 in number, alternate hexagons, ...	10 ,,

3. *E.* (*sp.*) Nilghiri Hills, S. India :—

Sheath whorls, alternate, . . .	24 ,,
Do. do. (upper part of plant), . .	8 ,,
Branch whorls (irregular), . . .	1-3 ,,
Fruit whorls, 10-12 in number, alternate hexagons, ...	8 ,,

4. *E. elongatum.* Mount Sarial, Georgia :—

Sheath whorls, alternate, . .	12-14 in each.
Fruit whorls, ,, . . .	10 ,,
Branch whorls, ,, . . .	8 ,,

5. *E.* (*sp.*) Western Texas and New Mexico :—

Sheath whorls, alternate, . .	24-30 in each.

6. *E. arvense.* Providence, R. I., and Berne :—

Sheath whorls, alternate, . . .	8 in each.
Fruit whorls (12-14 in number), alternate, ...	8 ,,
Branch whorls, ,, . . .	8 ,,

7. *E. limosum.* Providence, R. I. :—

Sheath whorls, alternate, . .	14-16 in each.
Fruit whorls, (12 in number), alternate, ...	16 ,,
Branch whorls, ,, . . .	10 ,,

8. *E.* (*sp.*) Ipswich, Massachusetts :—

Sheath whorls, alternate,. . . .	12 in each.
Fruit whorls, ,, ...	10 ,,

9. *E. sylvaticum.* Ipswich, Massachusetts :—

Sheath whorls, alternate, . . .	12 in each.
Branch whorls, ,, ...	10 ,,

10. *E. hyemale.* Mexico and Berne :—

Sheath whorls, alternate, . . .	16 in each.
Fruit whorls (9 in number), alternate, ...	8 ,,

11. *E.* (*sp.*) California:—

Sheath whorls, alternate,	16-24	in each.
Fruit whorls (28-9 in number), alternate,	16	„
Branch whorls, „	16-20	„

12. *E. debile.* East Indies:—

Sheath whorls, alternate,	24	in each.
Branch whorls, „	4	„

13. *E. giganteum.* Peru:—

Lower sheath whorls, alternate,	24	in each.
Upper „ „	12	„
Lower branch whorls,	24	„

14. *E. fluviatile.* Berne and Limerick:—

Sheath whorls, alternate,	24–30	in each.
Fruit whorls, „	16–20	„
Branch whorls, „	20–30	„

15. *E. arvense.* British:—

Branch whorls of barren stems,	13	in each.
Sheath whorls of fruitful stems,	8	„
Fruit whorls, alternate (14 in number),	8	„

From an examination of the preceding I conclude (rejecting the branch whorls, which are generally deficient in number), that the number of leaves in the alternate whorls of the Equisetaceæ are represented by the arithmetical series, whose first term is 4, and common difference also 4:—

4? 8, 12, 16, 20? 24, 28? 32?

—the terms to which I have appended queries being more doubtful than the others. I, at first, thought there were two series,

4, 8, 16, 32,

and

12, 24,

—formed by simple dichotomy; but the case of the Nilghiri Hill Equisetum proves the occurrence of 8 and 24 on the same plant, and the Californian Equisetum shows the concurrence of 16 and 24; thus proving that there is only one series of numbers, and that a series in arithmetical progression. The whorl of 8 leaves, which, next to that of 16, is the most common, is the only one related to the phyllotaxis of alternate-leaved plants.

III. *Filices.*

The rhizome, or root-stock of the ferns, presents many irregularities, the leaves being sometimes apparently alternate, but often truly arranged in whorls. The genus *Cyathea* or tree fern, from the Fee Jee Islands, is that which presents most analogy to the fossil plants of the Old Red Sandstone, so far as the leaf scars are concerned. These scars are arranged in quincunx, and are ovoid or elliptical lanceolate, according to the slowness or rapidity of the growth of the stem. Of the other ferns I have examined, the *Oleandra* presents the most marked examples of the whorled structure—

1. *Cyathea* (*sp.*) Fee Jee Islands:—

Root-stock of specimen examined, from four to five feet long, containing thirty-five rows of whorls, of three leaves each, placed alternately. The scars of this plant present the most striking resemblance to many of these found in *Lepidodendra.*

The angle of Divergence of the whorl is $\frac{1}{6}$.

By the suppression of alternate whorls, it would give the angle $\frac{1}{3}$ alternate-leaved, and by the additional suppression of one-third of the remaining leaves, it would give the angle $\frac{2}{3}$; in this latter case the reduction of leaves amounts to 67 per cent. of the original leaves.

2. ***Oleandra*** (***sp.***) **East Indies :—**

Leaves arranged in whorls of five each, two whorls placed close together, alternate, forming a complex or double whorl of ten leaves. Each such pair of whorls is placed 2 or $2\frac{1}{4}$ inches distant from the whorls above and below it.

Divergence = $\frac{1}{10}$.

3. ***O. neriiformis.*** **Luzon :—**

Leaves arranged in whorls of six each, placed two and two together, alternate, as in the preceding, and distant from those above and below them.

Divergence = $\frac{1}{12}$

4. ***O.*** (***sp.***) **:—**

Whorls of leaves in pairs, alternate, each whorl containing five leaves.

Divergence = $\frac{1}{10}$

5. ***O.*** (***sp.***) **Khasya Hills :—**

Whorls of leaves in pairs, alternate, each whorl containing five leaves.

Divergence = $\frac{1}{10}$

6. *O. Wallichii.* Nepaul and Assam:—
Whorls of leaves in pairs, alternate, five leaves in each whorl; the pairs of whorls are three inches apart.
Divergence = $\frac{1}{10}$

From the preceding facts we may infer that the whorled species of *Oleandra* are probably constructed on two types of whorls,

5, 6,

—both of which, by suppression of leaves, as already explained, may be reduced to the phyllotaxis of alternate-leaved plants.

7. *Aspidium filix mas.* Britain.
In this fern the root-stock exhibits an arrangement of leaves and leaf scars alternate, 7–8 in each whorl, as is well shown in the "Annals of Natural History," December, 1859, Pl. X., Fig. 9.

In the *Ferns* and *Clubmosses* the whorled arrangement of leaves, although following the usual law, appears to be insufficient to produce the division of the stem into nodes, as happens in the *Equisetaceæ* and some other natural families.

The next case to which I would direct attention is that of the Casuarineæ, represented by an old-fashioned genus, *Casuarina*, mostly confined to Australia and Tasmania, though it has some species in the East Indies and elsewhere. In this case the whorled structure is perfect, as much so as in *Equisetum*, although it is an Exogen, and apparently of a high order. Whether this group survives, like other Australian forms, as the representative of lost groups, or is to be regarded as a new and well developed type, the result of careful selection on the part of the goddess *Nature*, I leave for the consideration of those acquainted with the secrets of creation.

IV. *Casuarineæ.*

1. *Casuarina Lehmanniana.* Tasmania.
Leaves in whorls of 8, alternate.
Divergence = $\frac{1}{16}$

2. *C.* (*sp.*) Tasmania.
Leaves in whorls of 6, alternate.
Divergence = $\frac{1}{12}$

3. *C.* (*sp.*) Australia.
Leaves in whorls of 8, alternate.
Divergence = $\frac{1}{16}$

4. *C. Miguelii.* Tasmania.
Leaves in whorls of 8, alternate.
Divergence = $\frac{1}{16}$

5. *C. Grunii.* Tasmania.
Leaves in whorls of 10, alternate.
Divergence $= \frac{1}{20}$

6. *C. quatuorvalvis.* Tasmania.
Leaves in whorls of 10, alternate.
Divergence $= \frac{1}{20}$

7. *C. equisetifolia.* Canara, East Indies.
Leaves in whorls of 8, alternate.
Divergence $= \frac{1}{16}$

8. *C.* (*sp.*) Swan River.
Leaves in whorls of 4, alternate.
Divergence $= \frac{1}{8}$

9. *C. Preissiana.* Eliza Mountain, Freemantle.
Leaves in whorls of 4, alternate.
Divergence $= \frac{1}{8}$

10. *C. muricata.*
Leaves in whorls of 6, alternate.
Main stems have leaf scars of 7–8, alternate.
Divergence $= \frac{1}{12}$

11. *C.* (*sp.*) Fee Jee Islands.
Leaves in whorls of 8, alternate.
Divergence $= \frac{1}{16}$

12. *C. nana.*
Leaves of stem, smaller branches, and carpels of fruit cones, in whorls of 5, alternate.
Divergence $= \frac{1}{10}$

13. *C.* (*sp.*) Swan River.
Whorls of stem and fruit 7, alternate.
Divergence $= \frac{1}{14}$

14. *C.* (*sp.*) Philippine Islands.
Whorls of stem and fruit, 7, alternate.
Divergence $= \frac{1}{14}$

15. *C. distyla.* Tasmania.
Leaves in whorls of 7, alternate.
Fruit carpels in whorls of 7, alternate.
Divergence $= \frac{1}{14}$

16. *C. obesa.* Near town of Perth, a tree 35 feet high.
Leaves in whorls of 12, alternate.
Carpels in whorls of 12, alternate.
Divergence $= \frac{1}{24}$

17. *C.* (*sp.*) Swan River.
Leaves in whorls of 7, alternate.
Divergence $= \frac{1}{14}$

18. *C.* (*sp.*) Swan River.
Leaves in whorls of 5, alternate.
Fruit whorls of 5, alternate, showing ten vertical rows of opened carpels.
Divergence = $\frac{1}{10}$

19. *C.* (*sp.*) Swan River.
Leaves in whorls of 6, alternate.
Divergence = $\frac{1}{12}$

20. *C.* (*sp.*) (with spinous slightly twisted leaves). Swan River.
Leaves in whorls of 4, alternate.
Fruit, whorls of 4, alternate, showing eight vertical rows of carpels.
Divergence = $\frac{1}{8}$

21. *C.* (*sp.*) Swan River.
Leaves in whorls of 9, alternate.
Fruit whorls of 9, alternate.
Divergence = $\frac{1}{18}$

22. *C. Hugeliana* (35 feet high). Mount Brown, 900 feet.
Leaves in whorls of 8, alternate.
Divergence = $\frac{1}{16}$

23. *C.* (*sp.*) West Australia, between Perth and King George's Sound.
Leaves in whorls of 7, alternate.
Fruit whorls of 7, alternate.
Divergence = $\frac{1}{14}$

24. *C.* (*sp.*) West Australia.
Leaves in whorls of 8, alternate.
Fruit whorls of 8, alternate.
Divergence = $\frac{1}{16}$

25. *C. rigida.* Port Phillip.
Leaves in whorls of 7, alternate.
Divergence = $\frac{1}{14}$

26. *C. cristata.* Avoca.
Leaves in whorls of 12, alternate.
Divergence = $\frac{1}{24}$

27. *C. rigida.* Sealer's Cove.
Leaves in whorls of 8, alternate.
Divergence = $\frac{1}{16}$

28. *C.* (*sp.*) Common "She Oak" of Cape Riche, forming a large tree. Cape Riche, West Australia.
Leaves in whorls of 10, alternate.
Fruit, whorls of 10, alternate.
Divergence = $\frac{1}{20}$

29. *C.* (*sp.*) Cape Riche, West Australia.
Leaves in whorls of 9, alternate.
Fruit whorls of 9, alternate.

Divergence = $\frac{1}{18}$

30. *C.* (*sp.*) Vavau and Lifuka, Friendly Islands.
Leaves in whorls of 7, alternate.
Fruit whorls of 7, alternate.

Divergence = $\frac{1}{14}$

31. *C.* (*sp.*) Near Cape Riche, West Australia.
Leaves in whorls of 5, alternate.
Fruit whorls of 5, alternate.

Divergence = $\frac{1}{10}$

32. *C.* (*sp.*) Between King George's Sound and Cape Riche.
Leaves in whorls of 9, alternate.

Divergence = $\frac{1}{18}$

33. *C.* (*sp.*) Between King George's Sound and Cape Riche.
Leaves in whorls of 5, alternate; leaf scars on old stem and twigs very Lepidodendriform and Quincuncial.
Fruit whorls in 5, alternate.

Divergence = $\frac{1}{10}$

34. *C.* (*sp.*) Near Cape Riche, West Australia.
Leaves in whorls of 5, alternate.
Leaf scars of stem well marked.
Fruit whorls in 5, alternate.

Divergence = $\frac{1}{10}$

On comparing the number of leaves in the whorls, it appear that they may all be reduced to the following—

4, 5, 6, 7, 8, 9, 10, 12,

—the favourite numbers being

5, 7, and 8.

The angles of divergence are denoted by the reciprocals of thes numbers doubled, as already explained. In fact, the perfec whorl must be considered as made up of two adjacent whorls, th leaves of which, being intermediate, give double the number, c only half the interval between each for the angle of divergence.

V. *Proteaceæ.*

A very remarkable group of Exogens; the Proteaceæ posses among their number many whorled species, which supply us wit numbers additional to those of the Casuarineæ. Among the latte we found the number five, which forms so important an elemer in the other Exogens, and in the Proteaceæ we meet with the nun ber three, which is only less important.

1. *Lambertia ericifolia.* Swan River.
Leaves arranged in whorls of 3, alternate. Branches, flowers, and fruit follow the same law.
Divergence = $\frac{1}{6}$

As all the species of Lambertia which I have examined follow this law, it will be sufficient to give their names and localities.

2. *L. uniflora.* Swan River.
3. *L. multiflora.* Swan River.
4. *L. ilicifolia.* Swan River.
5. *L.* (*sp.*) Swan River.
6. *L.* (*sp.*) Near Cape Riche, W. Australia.
7. *L.* (*sp.*) " " "
8. *L.* (*sp.*) " " "
9. *L.* (*sp.*) King George's Sound.
10. *L.* (*sp.*) Sydney, N. S. Wales.
11. *L. inermis.* Between Perth and King George's Sound. Variety, with yellow flowers.
12. *L.* (*sp.*) King George's Sound.
13. *L. formosa.* N. S. Wales.

Divergence in all cases = $\frac{1}{6}$

14. *Brabejum* (*sp.*) Cape of Good Hope.
Leaves in whorls of 6, alternate.
Divergence = $\frac{1}{12}$
15. *B.* (*sp.*) Cape of Good Hope.
Leaves and branches in whorls of 8, alternate.
Divergence = $\frac{1}{16}$
16. *B. stellatum.* Cape of Good Hope.
Three specimens examined, from different collections; in all of them I found the number of leaves in the alternate whorls to be 7; giving thus a divergence of $\frac{1}{14}$.

VI. *Ericaceæ.*

In this large and important order of Exogens, the whorled law of arrangement universally prevails, the number of leaves in each whorl being—

2, 3, 4, 6, and occasionally 7.

These whorls all conform to the law laid down, and give rise to diverging angles of—

$\frac{1}{4}$, $\frac{1}{6}$, $\frac{1}{8}$, $\frac{1}{12}$, $\frac{1}{14}$.

In this natural order, 3 leaves in the whorl often occur, as also in the Proteaceæ; the other numbers of leaves in the whorls have been already met with; and that of 2 in the whorl, or opposite-leaved plants, is universal through the whole group of Exogens.

VII. *Cyclostigmaceæ.*

The fossil plants of the yellow sandstone of the county of Kilkenny occur, as they do in other parts of Ireland, in the sandstones lying immediately under the great mass of the Carboniferous limestone, which constitutes the most important member of our Irish fossiliferous rocks. They are found at Jerpoint, about a mile and a half south of the Abbey, on the roadside near the Corn-mill, on the way to Ballyhale, about 90 feet below the lowest bed of limestone, in rocks composed of red, white, and blue hone-stone, with Triboliths formed by rounded pebbles of pink quartz rubbing the hone-stone, and above the plant-beds a remarkable white grit conglomerate is found. Plant-beds, on the same geological horizon, are also found in the railway cutting at Ballyhale. They are found, however, in the greatest abundance, and in the best state of preservation, on the top of Kiltorcan Hill, near the railway station of Ballyhale. I believe the plant-beds on the summit of this hill to form an "outlier," and to occupy the same geological position with respect to the limestone as the beds at Jerpoint and those of the railway cutting.

The fossil plants here found have never been described except casually. They consist of remains of a large fern, called *Cyclopteris Hibernica* by Professor Forbes, associated with a large bivalve, named by him *Anodon Jukesii*, of undescribed dermal plates of a cartilaginous fish, probably a species of *Coccosteus*, and of numerous unknown plants, closely allied to *Lepidodendron*, and so named by Professor Forbes and M. Brongniart, the latter of whom has named a remarkable species, preserved in the Museum of the Royal Dublin Society *Lepidodendron Griffithi*. Others of these fossil plants have been named *Knorria*, and a large undescribed group remains, to which I propose to give the name *Cyclostigma*.

Cyclostigmaceæ.—Natural order of fossil plants, found in the lowest beds of the Carboniferous system; part of the oldest Flora known to have existed on the globe; probably closely allied to the orders described as Knorria, Lepidodendron, and Sigillaria; known only by their leaf scars and leaves, which were arranged in alternate whorls; plants not jointed at the whorls; the leaf scars perfectly circular, showing in many cases a minute and well-marked dot in the centre, probably coinciding with a central bundle of woody tissue; many of the larger plants show traces of a thick central woody axis, like that found in Stigmaria; stems much crushed and flattened, as if they were not woody throughout. Approach nearest to Stigmariæ, from which they differ in the leaf whorls being further apart, and more distinct.

LECTURE XI.

NEOZOIC EPOCH—CLASSIFICATION OF REPTILES—HISTORY OF REPTILES—CHELONIANS—SAURIANS—PTERODACTYLIANS—ENALIOSAURIANS—LABYRINTHODONTS.

DURING the remaining part of these Lectures I must direct your attention to the last or Neozoic period of the earth's history, which, although it occupies, as we have reason to believe, only one-fourth part of the total time consumed in the deposition of the aqueous rocks, possesses for the zoologist or naturalist a degree of importance far greater than the whole of the remaining three-fourths of the earth's history. This is one consequence of the law that I have so often called your attention to, that as the world grew older, and its physical conditions altered, and it was prepared by its Creator for more varied and diversified forms, those varied and diversified forms appeared upon it. And, by virtue of a law that appears to determine the duration of genera and species, the more perfect and advanced these creatures became in their organization, so in proportion they became shorter-lived geologically, or continued for a shorter period of time upon the globe. Thus we find the imperfect forms of palæozoic life spreading over the whole surface of the earth, so that it is

difficult to tell the fossils of this period found in one part of the world from the fossils found in another; whereas in the Neozoic period, with which we are now concerned, each bed of rocks, and, I may add, each particular country has its peculiar and characteristic fossils, which are easily distinguished from fossils of other portions of the earth, formed during the same time. This geographical diversity in organic beings is now at its maximum. Physical conditions regulate completely the organic life of each part of the earth's surface, and from the earliest time to the present this law has been in incessant operation. The sameness, therefore, that characterizes the rocks and fossils of the Palæozoic period in different and distant countries is not to be looked for by us in the Neozoic period, during which the physical conditions of different regions of the globe became very diverse.

In the Neozoic period I include all the formations more recent than the Permian. You will remember that the Permian includes that group of sandstones which cover in the coal measures. It used to be called by the older geologists in England the Lower New Red Sandstone. They divided the Red Sandstones of England into three groups. These consisted of the Old Red Sandstone, which belongs to the Devonian or Lower Carboniferous period, and the New Red Sandstone, which was divided into the Lower and the Upper New Red Sandstone,—the Lower New Red Sandstone being now called the Permian, and Upper New Red, the Trias.

Commencing with the Permian strata, which constitute the last of the Palæozoic period, we travel up through the Triassic, the Liassic, the Oolitic,

the Cretaceous, and the Tertiary. In most books on geology you will find each of these epochs or periods treated at great length; but when we add them all together, the whole period of time which they indicate is only one half that of the Palæozoic period, and one-fourth of the whole lapse of time since aqueous rocks began to be formed on the surface of the globe.

I have already called your attention to the facts that justify the peculiar attention bestowed upon these strata by naturalists; for we are to measure the importance of strata, not so much by the length of time that they took to form, as by the variety of organic life that is found in them. The two older periods which we have already discussed, the Lower and Upper Palæozoic, represent equal intervals of time; and each of them separately is equivalent to the Neozoic. We found the first of these periods to be characterized, as shown in the Diagrams, p. 104, by the extraordinary developement which the Crustaceans acquired during it, so that they became 24 per cent. of the whole coexisting creation, and 37 per cent. of all fossil Crustaceans, and were created at the rate of forty species per mile of rock; and we found the second part of the Palæozoic period to be characterized by the extraordinary importance which the Fishes acquired during that time. They, in their turn, attained during that period a proportion of 21 per cent. of the whole co-existing creation, and 24 per cent. of all the Fossil Fishes, but were not produced as quickly as in the Neozoic period.

In the Neozoic period which we have now to speak of, you observe that we have two curves acquiring an importance comparable with those of the

Crustaceans and the Fishes. At the commencement of the Neozoic period, the Reptiles suddenly rise to a degree of importance comparable with that of the Fishes and the Crustaceans in former times. Having reached 23 per cent. of the existing creation, and 42 per cent. of all fossil Reptiles, and a rate of creation of ninety species per mile, they fall off again as we approach the Tertiary period.

On referring to the curves of Mammalia, we find that at the close of the Neozoic period the Mammals attained a degree of importance comparable with that of the Reptiles, the Fishes, and the Crustaceans, in succession. During this Ontozoic period, the Mammals formed 22 per cent. of the existing fossils, 60 per cent. of all fossil Mammals, and were produced at the rate of thirty-four species per mile of rock.

In this day's Lecture I shall draw your attention to the Reptiles, and to the remarkable laws which their life-history on the surface of the globe enables us to trace; and in a future Lecture I shall call your attention to the equally remarkable laws that regulate the preponderance of the Mammals at the close of the Neozoic period.

The Reptiles acquired their extraordinary zoological importance at the commencement of the Neozoic period, or, to speak more precisely, during the deposition of the Lias beds. We have reason to believe that at no time before or since the deposition of the Lias beds did Reptiles play so important a part on the surface of the globe as they did in that time.

The first good classification of Reptiles proposed was that of Alexander Brogniart, who divided

them into Chelonians, Ophidians, Saurians, and Batrachians; and he placed these four groups in what he conceived to be the order of their zoological dignity and importance. The investigations of geologists have shown us that it is impossible to restrict the Reptiles within these four groups; and we are forced to add to them three others which are represented by fossil genera, namely, the Pterodactyles, the Enaliosaurians, and the Labyrinthodonts. I shall have to call attention briefly to each of these seven groups. It is also to be observed that the first four groups proposed by Brogniart are not of equal importance. The Batrachians—represented by the frogs—differ more widely from the tortoises, the lizards, and the snakes, than these three differ from each other. Therefore they are not to be regarded as groups of equal importance; and some persons have, on this ground, proposed a totally different subdivision of the whole class.

The classification adopted by us is the following:—

CLASS REPTILIA.

ORDERS.

I. CHELONIANS—(αἱ χελῶναι).
II. SAURIANS—(οἱ σαῦροι).
III. PTERODACTYLES—(τὰ ἑρπετά τοὺς δακτύλους πτερωτοὺς ἔχοντα).
IV. ENALIOSAURIANS—(οἱ σαῦροι ἐνάλιοι).
V. LABYRINTHODONTS—(τὰ ἑρπετά τοὺς ὀδόντας λαβυρινθωδεῖς ἔχοντα).
VI. OPHIDIANS—(οἱ ὄφεις).
VII. BATRACHIANS—(οἱ βάτραχοι).

The Batrachians are evidently inferior to the Chelonians, Saurians, and Ophidians, because they undergo metamorphoses, and at an early stage of

their existence breathe by gills instead of lungs. This clearly establishes them as an inferior group; for the aquatic animal is by hypothesis inferior to the terrestrial. They also differ materially in the organs of circulation—in the number of auricles and ventricles of the heart; but as these are characters that do not come under the cognizance of the geologist,—the heart being a soft organ, and never preserved fossil,—we have no concern with such characters beyond taking note of the fact that they justify what geologists allege as to the complete separation of this group from the others.

In discussing the history of Reptiles on the surface of the globe, or the history of Fishes, or of any other group, it is impossible for us not to feel the greatest interest in the question whether there was a progress or a retrogression in the forms of life; and in considering this question, it must be admitted that we find great embarrassment and difficulty in fixing upon some principle according to which we shall define what is progression, and what is retrogression. Many laws are laid down by some naturalists as laws of progression, that by others are denied to be so. Let us take an example in the case of Fishes to which I have already directed your attention. The question whether the cartilaginous or the bony skeleton necessarily carries with it a higher or a lower organization is one that, I confess, does not appear to me to be yet solved; because, although we grant the general principle contended for by those who say that the bony skeleton indicates the more perfect animal, yet we find this theory sadly interfered with by the fact observed with regard to some of the cartilaginous Fishes, that they are viviparous, and not oviparous,

which of course, from another point of view, and other considerations, marks them out as a much higher group. Again, the principle has been attempted to be established, that if we can find in the history of life upon the globe that the forms of creatures followed the embryological developement of the individuals, and if we can consider those as permanent forms in the early history of the globe that were like the earlier forms of individual history, we may consider a law of progression as established. This, to a certain extent, has been found to be the case; but it would be quite a misstatement of facts to assert that any such general law could be made out from the history of either Fishes, Reptiles, Mammals, or any of the great groups. It may be possible to go some way towards establishing such a law in the case of the Crustaceans and Echinozoa; but certainly in the case of the Fishes, Mammals, and Reptiles—the most important vertebrate groups—the supposed law has not been established. I shall not therefore trouble you much with a discussion as to which of the seven groups of Reptiles is the most highly organized. We are all agreed that the Batrachians are the lowest; and there is strong reason for believing that the Chelonians are the highest; but to establish a regular order with relation to their zoological dignity and importance would seem to be very difficult.

I. Chelonians.—The first order of Reptiles, the Chelonians, is well known, and includes the tortoises and the turtles. Their body is protected on the back by an expansion of the ribs and transverse processes of the dorsal vertebræ, so as to

form a complete covering for the back, called the *carapace*; and the belly is protected by a corresponding developement of the sternum, which is called the *plastron*. The carapace and the plastron completely protect these animals. Some naturalists will tell us that this very consolidation of the bones is in itself a perfection. They will say with regard to some animals—as, for example, it has been said with regard to Fishes—that the disappearance of cartilage, and the occurrence of solid bone in place of the cartilage forming the vertebræ, is a sign of increasing perfection. It appears to me that this argument is not correct; that we might as well say that a child with its knee joint anchylosed had an important advantage over other children. No general rule can be laid down with respect to such cases. In every instance you must examine what the objects are for which the structure was given, and whether a moveable structure or joint, or bones soldered together, will answer that purpose best; but no such general rule can be laid down as that the presence of more or less bones, free or jointed together, constitutes, of itself, more or less perfection.

There is one peculiarity in many of our modern Reptiles which I readily admit to be a sign of greater perfection, viz. that the bodies of the vertebræ are convex on the posterior surface, and concave on the anterior. Now, such a series of vertebræ, in which the surfaces form ball and socket joints, is evidently a more perfect form of spinal column than a series of double concave vertebræ, which I showed you in a former Lecture was a characteristic of Fishes. This double concave form of vertebræ, which is the ichthyic or Fish type, constantly appears in many of the ancient Reptiles.

The Chelonians are without teeth, and have their jaws furnished with horny edges or beaks, that answer the purpose of prehensile teeth. The brain case is small, the os quadratum united to the temporal bone, and the occipital bone articulates with the atlas by means of a single condyle, corresponding to the body of the vertebra.

The glenoid cavity for the head of the humerus is formed of the three typical bones, clavicle, coracoid, and scapula; and the acetabulum of the pelvis for the head of the femur is formed of the three corresponding typical bones, pubis, ischium, and ilium. The analogy between the shoulder and pelvis is, indeed, better observed in Reptiles than in any other class of Vertebrates.

The Chelonians are unknown before the Neozoic period, in the early part of which they appeared, together with the inferior orders of the Class.

Their geographical distribution, geologically, in the North of Europe and Asia, adds another proof to the many we possess of the fact, that in earlier periods the earth enjoyed a much higher temperature than at present.

The discovery of enormous fossil tortoises in the Sub-Himalayan beds shows that the third law laid down in the last Lecture extends to the Chelonians. Some of these fossil tortoises, described by Cautley and Falconer, possessed a carapace twelve feet by six feet, which must have corresponded to an animal from eighteen to twenty feet in length; and the bones of the legs were as massive as those of the rhinoceros. Some naturalists believe, from an examination of the Hindoo mythology, that these gigantic tortoises may have lived on from the Mastozoic into the Anthropozoic period in Hindustan.

The largest of these monsters is known by the name of the *Colossochelys Atlas*.

Fossil remains of tortoises not much smaller than those of India have been found also in South America, associated with the remains of the Post-tertiary mammal Megatherium.

II. Saurians.—The Saurians are distinguished from the Chelonians by the want of a carapace and plastron, from the Ophidians by their four limbs, and from the Batrachians by their scaly skin; they do not possess the wings of the Pterodactyles, nor the paddles of the Enaliosaurians, nor the double occipital articulation and complicated teeth of the Labyrinthodonts.

They are divided by geologists into the three following Families:—

1. DINOSAURS. . . .	Long bones, furnished with marrow; feet like those of the pachyderm mammals; sacrum formed of at least five anchylosed vertebræ; lower jaw admitting of horizontal motion for trituration, and therefore implying the existence of powerful pterygoid muscles; femur furnished with three trochanters.
2. CROCODILIANS. . .	Body covered with bony plates; jaws furnished with conical teeth, placed in sockets; feet palmate; sacrum formed of two vertebræ.
3. LACERTIANS. . . .	Body covered with horny scales; teeth rarely placed in sockets; sacrum formed of few vertebræ.

1. Among the Dinosaurs, the best known fossil genera are the Megalosaurus, the Hylæosaurus, and the Iguanodon. They are remarkable on account

of their great size, and their resemblance to the larger mammals. This resemblance is particularly shown in the sacrum, which is formed of five vertebræ; whereas in all other reptiles, living or fossil, the sacrum is never formed of more than two vertebræ.

The *Megalosaurus Bucklandi*, which is the best known species of the genus, was provided with a short muzzle, and carnivorous teeth (concavo-convex, with crenulated antero-posteral edges), curved backward, so as to hold the prey when once seized. This Reptile was upwards of thirty feet in length. It has been found in the Stonesfield Slate in England, in the Caen limestone, and in the Oolitic beds of Rochelle and Soleure.

The *Hylæosaurus armatus* is so called from the singular crest of bony spines which formed a protection to the Reptile, placed along the dermal surface corresponding to the spines of the upper dorsal and lower cervical vertebræ. Judging by the shape of their crowns, its teeth indicate an herbivorous Reptile, and one that probably fed, like the Siberian mammoth, habitually on twigs of trees. His skin was protected by elliptical bony scales, and by the crest of spines already described. This Reptile has been found in the Wealden beds of England, and was at least twenty-five feet in length.

The *Iguanodon Mantelli* attained a length of sixty feet, and has been found in the Wealden beds, and in the Lower Greensand formation in the south-east of England. Its teeth show the remarkable appearance of crowns worn down by trituration and mastication of vegetable food, and resemble those of Mammals rather than those of Reptiles in their mode of developement. Its humerus and femur

were nineteen inches and thirty-three inches, respectively, showing that the Reptile was higher in the haunches than in the shoulders. It is considered to have exceeded the bulk of the elephant eightfold. It is perhaps worthy of remark, that among existing Reptiles, the only one capable of forming a personal attachment to man is the Iguana of the Western Indies, which in its dwarfed condition retains many of the traits of the high organization of its predecessor, the gigantic Iguanodon of the Weald.

2. The Crocodilians are divisible into three groups, according as the bodies of their vertebræ, considered from before backwards, are

1. Concavo-convex.
2. Biconcave.
3. Convexo-concave.

The living Crocodilians, viz., the Crocodile, the Cayman, and the Gavial, belong to the first of these divisions, while the other two are found represented frequently among fossil Crocodilians.

The form which is concave in front and convex behind differs essentially, as a mechanical apparatus, from the form convex in front and concave behind, as I shall easily show you. The ball and socket joint, where the concavity is in front, is evidently constructed with reference to a fixed point behind, and to a movement in front; whereas the structure which is convex in front and concave behind* has reference to a motion in which the point in front is fixed, and the greatest amount of motion is given behind.

How far either of these structures is to be con-

* The convexo-concave form of vertebra is that which prevails in the tails of the larger herbivorous mammals.

sidered as higher or lower than the other, it is impossible for us to say. I have no doubt that, if we knew the habits of the different fossils that possessed those structures, we should find them to correspond to different mechanical contrivances. The biconcave form of vertebra is the rarest, and seems to indicate an approach to the Ichthyic type in the Reptiles that possessed it. It must have been accompanied by a greater pliability of the vertebral column, and greater motion, not only laterally, but upwards or downwards, and in any direction ; but it appears to me that this is not an advantage, because it is accompanied with a proportionate weakness and want of determinate motion in the spinal column, which is indicative of imperfection.

The best known of the fossil Crocodilians is the *Teleosaurus Chapmanni*, found by Mr. Chapman, near Whitby, in 1758 : other specimens of this species were afterwards found at Saltwich, all of which belong to the beds of the Upper Lias, and correspond with the maximum developement of the Saurozoic epoch ; one of these reptiles was eighteen feet in length. Another species, called the *Teleosaurus Cadomensis*, has been found in the Oolite of Caen; it was upwards of twenty feet in length, and was described by Cuvier as the Gavial of Caen.

The Teleosaurs possessed biconcave vertebræ; they resembled our modern Gavials, but possessed a larger number of ribs, and were better protected by bony scales. They were probably marine, and lived on fish.

3. The most remarkable of the fossil Lizards is the *Mœsasaurus Camperi*, so called from its having been found, for the first time, in 1780, near

Mæstricht, on the Meuse, in the upper chalk beds of that locality. This reptile was first described by Adrian Camper, and afterwards by Cuvier, who showed its affinities to be closer to the Monitors and Iguanas, than to any other order of Reptiles. Its vertebræ are concavo-convex; the cervical, dorsal, and lumbar together are thirty-four in number, and the caudal 97; the costal articulations are wanting on the dorsal vertebræ, from the middle of the back, indicating great flexibility of the body. The tail was compressed vertically, and formed a powerful propelling organ in swimming; the arm and fore-arm bones, also the thigh and leg bones, are compressed, as if they had formed paddles; and the animal was probably marine in its habits, as well as carnivorous. It reached the length of twenty-five feet.

III. Pterodactylians.—This remarkable Order of Reptiles is known to us in the fossil condition only; and from their resemblance to birds and bats, these animals were not considered as Reptiles by the older naturalists. They are, however, readily distinguished from birds by the presence of teeth, and by the form of their vertebræ; and from mammals by the equal and conical form of all their teeth, by the smallness of the brain case, the number of phalanges different in each finger, and by the essentially reptilian structure of the shoulder joint. The wings of these flying Reptiles are formed on a principle essentially distinct from that of the wings of birds, or mammals. In birds the fingers are united, and serve for the support of the wing pinions; and in the bats, while the thumb remains rudimentary, the phalanges of the last four fingers are elongated, and sustain the

stretched membrane that serves the purposes of a wing; on the other hand, in the Pterodactylians, the last of the five fingers has its phalanges elongated, and the first four remain of the normal size. These Reptiles had from seven to eight cervical vertebræ, from thirteen to fifteen dorsal, two or three lumbar, six sacral, anchylosed, and from ten to fifteen caudal vertebræ. The long bones and vertebræ are hollow, and traversed by air tubes, like those of the bones of birds; they possessed five or six carpal bones, five metacarpals, and five fingers, composed of one, two, three, four, and four phalanges, respectively. This structure indicates a delicate power of feathering the wing either in air or water, and is similar to the structure of the webbed feet of the cormorant, gannet, and other powerful and dexterous divers.

The Pterodactylians occur from the Lias to the Wealden and Chalk beds; and it is a remarkable fact, that whereas the Pterodactyles of the older Lias beds did not exceed ten or twelve inches in length, the later forms found fossil in the Greensand and Wealden beds must have been at least 16½ feet long.

IV. Enaliosaurians.—These are the most remarkable of all fossil Reptiles, uniting as they seem to do almost incompatible characters; for they possess the double concave vertebræ of fishes, the teeth of crocodiles, the bodies of lizards, and the paddles of the cetaceans. Their principal characters are: double concave vertebræ, broader than long; conical teeth, without basal cavity; four short and flattened limbs, with fingers formed of many discoidal, often hexagonal bones, arranged as in the cetaceans. These

Reptiles flourished in the Triassic and Liassic periods, and continued to exist to the end of the Cretaceous period. They are therefore essentially Neozoic Reptiles; and their prevalence during the period of the deposition of the Lias aided materially in giving the character to the life of that period which has caused it to be designated as the Saurozoic epoch.

The most remarkable genera of the Enaliosaurs are the Ichthyosaurus and Plesiosaurus.

The Ichthyosaurus is well shown in Fig. 35, which is drawn from a fine specimen of *Ichthyosaurus communis*, found at Lyme Regis, and preserved in the Geological Museum of Trinity College. This fine specimen shows well the essential peculiarities of the genus and species. From the mode of fossilization, the under side of the lower jaw and its articulation are well seen, also the amalgamation of the radius and ulna; and of the tibia and fibula, with the carpal, tarsal, and phalangeal bones, which is characteristic of the species.

In Fig. 36 a fine specimen of *Ichthyosaurus platyodon* is shown; it also is taken from a fossil found in Lyme Regis, and preserved in the Museum of Trinity College. While resembling the former species in general outline, it differs from it in many particulars, such as the shape of the head, arrangement of teeth, and lesser number of finger bones in the paddles.

In Fig. 37 I have represented a very remarkable specimen of a young or tadpole Ichthyosaurus, found at Boll, in Wurtemberg, and preserved in the Museum of Trinity College. It has no paddles, and seems to be the undeveloped condition of the perfect Ichthyosaurus. If this view be correct, it

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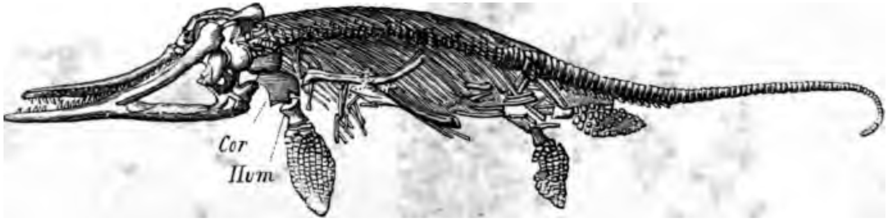
Fig. 35.



ICHTHYOSAURUS COMMUNIS.

(Museum of Trinity College, Dublin.—Found in the Lias of Lyme Regis, Dorsetshire.)

Fig. 36.

ICHTHYOSAURUS PLATYODON.

(Museum of Trinity College, Dublin.—Found in the Lias of Lyme Regis, Dorsetshire.)

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Fig. 37.

YOUNG OF ICHTHYOSAURUS COMMUNIS.
(Museum of Trinity College, Dublin.—Found in the Lias of Boll, in Wurtemburg.)

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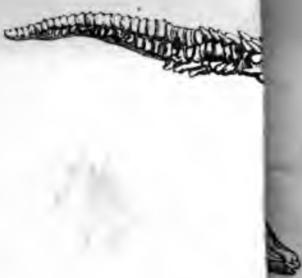

ould follow that some of the Enaliosaurs underent metamorphoses, like the Batrachians.

One of the most remarkable peculiarities in the natomy of the Ichthyosaurs, is that exhibited y the sclerotic plates of the eyeball, which are often as many as seventeen in number. These plates surround the pupil in a conical form; and during life were capable of exerting a pressure on the cornea that must have altered its shape considerably under varying circumstances, and so have accommodated the eye to the varying distances and refractions of the two media, air and water, in which the eye had to be used. Such a structure in the eye is now found only in certain turtles, tortoises, lizards, and birds.

Some of the largest forms of Ichthyosaurus must have exceeded thirty feet in length.

The Plesiosaurus is easily distinguished from the Ichthyosaurus by its long neck, and is found in the same geological deposits. Like the Ichthyosaurus, it was a marine carnivorous Reptile, and in its structure unites the head of the lizard, the neck of the swan, the trunk of an ordinary quadruped, the ribs of the chameleon, and the paddles of the whale.

It was smaller than the Ichthyosaurus, and probably frequented shallower water, where its long neck would serve important uses in fishing for its food.

The largest known species, *Plesiosaurus Cramptoni*, is figured in Fig. 38, from a specimen found in the Lias beds of Kettleness, near Whitby, in Yorkshire, and preserved in the museum of the Royal Dublin Society. On comparing this figure with those of the Ichthyosaurus, the separation of the radius and ulna from the carpal bones, and of the fibula and tibia from the tarsal, is very marked, as compared

with the corresponding bones in the Ichthyosaurus. This anatomical peculiarity indicates a more perfect mechanism in the paddles, and, combined with the advantages of the long neck of this Reptile, leads to the conclusion that, although a smaller, it was a more highly endowed animal than its formidable rival.

The total length of the *Plesiosaurus Cramptoni* was twenty-two feet four inches.

One of the most perfect specimens of Plesiosaurus known to geologists is shown in Fig. 39. It was found in the Lias marl of Lyme Regis, by Miss Anning, and is now preserved in the fine collection of the Earl of Enniskillen at Florence Court. It is named *Plesiosaurus macrocephalus*, and shows the structure of the paddle better, perhaps, than any other known specimen.

The unique specimen drawn in Fig. 40 is preserved in the British Museum, and was found at Street, near Glastonbury. It is five feet seven inches in length, and shows beautifully the ventral aspect of the bones of the *Plesiosaurus dolichodeirus*. It is particularly remarkable for the perfect symmetry it discloses between the pelvic and shoulder arches, as exhibited by the pubes, ischium, and ischiado-pubic, or obturator foramen of the pelvis, and the clavicle, coracoid, and claviculo-coracoid foramen of the shoulder.

V. Labyrinthodonts.—The first remains of this remarkable order were found in the Keuper Sandstone of Wurtemburg, and were described by Jæger under the name Mastodonsaurus.

They are called Labyrinthodonts from the peculiar and complicated arrangement of the cement

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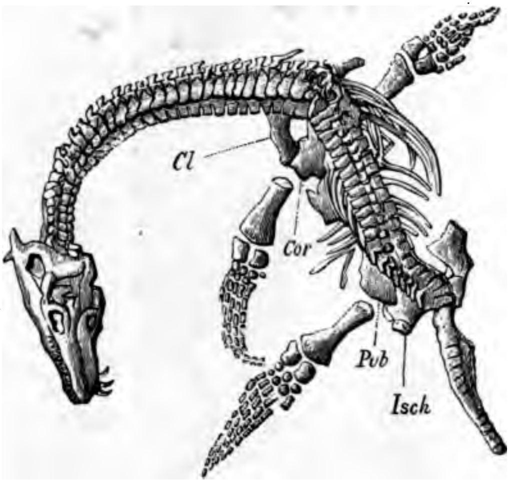
FIG. 39.



PLESIOSAURUS MACROCEPHALUS.
Museum of Earl of Enniskillen.
(Found in the Lias of Lyme Regis, Dorsetshire.)

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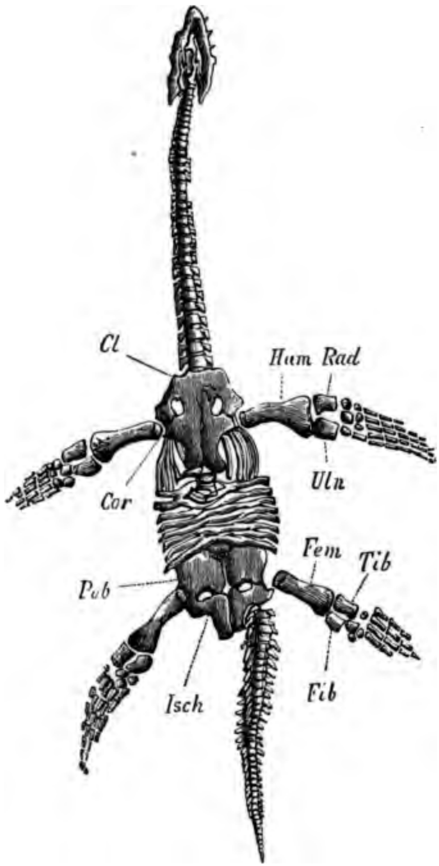
FIG. 40.



PLESIOSAURUS DOLICHODEIRUS.
(British Museum—Found in the Lias of Street, near Glastonbury.)

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Fig. 41.

CHEIROTHERIUM ANGLORUM—RESTORED.

layer of the teeth, and are very closely connected with the Batrachians. In the Sandstones of Storton, in Cheshire, and on the New Red Sandstone of parts of Warwickshire, footprints are found which are believed to have been made by gigantic Batrachians belonging to this order; they are known by the name of Cheirotherium. Footprints of the same character have been found in Thuringia, in the quarry from which the cathedral of Cologne was rebuilt. Until very recently not more than eight genera of Labyrinthodonts were known to occur in Europe, and the researches of Professor Dawson in the Coal Measures of Nova Scotia had yielded several additional genera—the first of which, Dendrerpeton, was established for a small Batrachian which had been found in the hollow of the trunk of a large Sigillaria. Since the publication of the First Edition of this Manual, the important discovery of fossil remains in the Coal Measures of the Queen's County has brought to light no fewer than six new genera, several of which prove, by their well ossified vertebral column, that these forms were not necessarily of low organization.

While among the Labyrinthodonts there are probably to be found representatives of the Batrachian order Ophiomorpha, and of both the caducous and deciduous sub-orders of Saurobatrachia, it is remarkable that the Anurous Order, represented by the Toad and Frog, is as yet undiscovered, unless, indeed, the astonishing fossil, for the restoration of which we do not hold ourselves responsible, shown in Fig. 41, may be regarded as such!

VI. Ophidians.—These Reptiles, so well known to us as snakes, did not exist before the Tertiary

epoch, and may be regarded as quite recent in the history of the globe.

VII. Batrachians.—The Batrachians or Amphibians, like the Ophidians, are comparatively recent, and their remains do not occur in strata older than the Tertiary beds. They are essentially, like the Ophidians, Ontozoic animals. This fact has a remarkable meaning in guiding and limiting our speculations as to the progress of life on the globe; for it cannot be doubted that the Ophidians and Batrachians are the lowest in organization of all the orders of Reptiles; and yet they make their appearance long after the higher forms of reptilian life had passed away—a fact irreconcileable with any theory of progressive developement of life by merely natural causes.

There is no difficulty whatever in coming to the conclusion that serpents and frogs are not the highest of Reptiles in the scale of organization. In fact, the absence of limbs in the serpents, and the fact that they consist simply of a spinal column with ribs, and that the number of ribs and of vertebræ appears to be a matter of indifference, shows a very low type of organization. They seem relatively as low in their organization as the endogenous plants provided with an indefinite number of joints. As to the Batrachians, they also are of inferior organization; and yet it is well known that the serpents and the Batrachians were amongst the creatures most recently introduced on the surface of the globe.

There are only one or two serpents known to be fossil, and they belong to the most recent of the Ter-

tiary periods; so that the argument for progress derived from the fact that the Chelonians appear latest on the earth's surface would appear to be destroyed by the fact that the serpents and the frogs are also among the latest to appear.

LECTURE XII.

ORNITHICHNITES—CONNECTICUT FOOTPRINTS—DINORNIS—ECHINOZOA—CRINOIDS—ASTEROIDS—ECHINOIDS—HISTORY OF ECHINOZOA—FOSSIL CRINOIDS—FOSSIL ASTEROIDS—FOSSIL ECHINOIDS.

In the last Lecture we considered the history of fossil Reptiles, and I showed you that these animals follow the same law of developement in the history of the globe that we found to prevail in the case of several other groups. In this Lecture I shall ask your attention to the history of the fossil Birds, and Echinoderms.

With regard to fossil Birds, the facts that we are acquainted with are few and scattered, but are of the highest interest and importance. It is natural to suppose that the fossil remains of Birds should be rarer in any deposits than the remains of other animals, because, being inhabitants of the air, they would naturally have escaped more readily from the risk of inundation on land; and their remains, being carried out to sea, would finally sink into the mud deposited at the bottom, and so become fossil. This remark explains the great rarity of fossil bones of Birds, and in fact, if we except the few Birds that happened to die in the water, and escaped being devoured before they were deposited in the mud at the bottom, it would be difficult for us to imagine

under what circumstances the remains of Birds could be deposited. But we have obtained most interesting and important information respecting the former existence of this class of animals by means of their footprints, or physiological fossils which we now call Ornithichnites, denoting that they are the footprints of birds.

The most valuable information we have on this subject has come to us from North America. There is a remarkable bed of sandstone in that country occupying a large tract, upwards of 200 miles long, in Connecticut, by about ten miles wide at its outcrop, where it can be examined and explored by geologists. It is not yet agreed among geologists to what particular group of sandstones it should be referred. It is newer than the Coal Measures, and older than the Lias. It might therefore be one of the group of beds which in Europe we call Permian or Triassic. It is remarkable as being the rock in which the footprints of Birds are found in the greatest abundance, and in which the results derivable from the exploration of these footprints have had the greatest amount of interest attached to them. Strange to say, amongst the footprints of Birds the largest are also the commonest. The most common footprint in this sandstone is that of a three-toed bird (*Brontozoon giganteum*), presenting alternate impressions of the right and left foot on such a gigantic scale, that from the tip of the inner to the tip of the outer toe measures nearly twelve inches. The stride from the footprint of right foot to the footprint of right foot varies from six to eight feet. This Bird must therefore have had a linear dimension four times that of an ostrich; and as the bulk or weight of a bird or of an animal supposed to be

symmetrically constructed varies as the cube of its linear dimensions, this would be equivalent to its being sixty-four times the weight of our present largest known species of ostrich.

You will therefore observe that the remarkable and curious fact appears, from the earliest evidence we have of the existence of Birds, that they were introduced on a scale of size and dimensions which has never since been equalled or repeated. They corresponded very nearly at this period of their maximum developement with the maximum of reptiles; but it would be trifling with figures to pretend to draw any curve to represent the developement of Birds. The facts known respecting them are so few and scattered, that we are obliged to take them as isolated facts, and to judge of them by what we observe with regard to other creatures.

Professor Hitchcock, who first stated that the American footprints were those of Birds, was naturally very cautious before he published his discoveries. To announce a bird sixty-four times the weight of an ostrich, and to base its existence solely on its footprints, was an attempt that required the greatest care. But fortunately in the footprints of Birds we have, from their anatomical peculiarities, little or no difficulty in determining that they are Birds. In most Birds three of the toes are pointed forwards, and the fourth toe does not reach the ground, but is pointed backwards, and makes no impression on the ground. Measuring from the inner to the outer side of the foot, such Birds present the remarkable peculiarity that the first finger of the foot has two phalanges, the second has three phalanges, the third has four, and the fourth has five. With the exception of some lizards,

there is no such known arrangement of the phalanges. But as the first toe, which is placed behind, makes no impression as a footprint, we should expect to find in the footprints of the Birds, three, four, and five, as the impressions of the separate phalanges in the sand. But on observing the footprints of recent Birds it is found, as is well known, that the two distal phalanges make only one impression on the ground as the Bird walks; they are thrown into one by the impression of the soft part of the foot. Therefore two, three, and four are the numbers of the phalanges we should expect to find in footprints of Birds. This is the invariable characteristic of the footprints in the Connecticut sand. Thus, through the evidence afforded by this remarkable anatomical law of the footprints of Birds, we arrive with perfect certainty at the conclusion that the footprints even on this gigantic scale were those of Birds; for the supposition that they were those of a lizard is at once excluded by the fact that they evidently belong to a two-footed animal.

On the subject of this Connecticut sandstone I would say a few words as to footprints and physiological impressions in general. They are formed by the animals walking over the wet sand, on which we may suppose the returning tide to deposit the clay or mud that makes a natural cast of the impression, and so preserve it for geologists. One would expect in such a case that the upper surface of the stone would contain the best impression; the upper surface was clearly that on which the animal walked, and you would therefore expect that it would retain the most perfect cast of his footprints. But this we find not to be the case. The upper surface of the stone is pressed upon by the animal's foot. The

particles of sand or mud forming the soft strand are pressed together, and acquire a sort of nodular or concretionary structure, so that afterwards, when it becomes solidified into rock, the impression of the foot tears out of the stone in a coarse and rough manner. But in the under surface of the slab, where we have the cast of the impression taken while still fresh in the sand by the layer of mud next laid over it we have a perfect impression, without any such physical cause coming into play to destroy or injure it. Consequently, although the impression is reversed, we have on this surface of the slab a perfect impression of the Bird's foot, in which the different phalanges are distinct, and capable of being counted.

Very often in these slabs we have the traces of an ancient shower accompanying the footprints of Birds. In the upper surface of the stone it is rare to find the appearance of rain; but nothing is more common than to find on the under surface a natural cast formed by the pits of the rain drops as they fell, scattered all over the stone.

The proof of the existence of Birds in the earlier part of the Neozoic period does not, however, rest altogether on the evidence afforded by footprints. The bones and impressions of the plumage of a remarkable Bird have been discovered in the lithographic stone of Solenhofen; and the name of *Archæopteryx lithographica* has been given to this earliest specimen of fossil Birds. Its most remarkable anatomical peculiarity consists in the elongation of its caudal vertebræ into a true tail, furnished with bipinnate feathers, and which attained a length nearly half that of the entire spinal column.

From the facts already stated respecting the fossil birds of America, we are entitled to come

to the conclusion that Birds of enormous size formerly existed on the globe, and that from the time they were introduced to the present time they have not ceased to exist. These birds, as far as we know anything respecting them, appear to have been allied in their habits to the ostrich. The *Brontozoon giganteum* of Professor Hitchcock, the largest that has yet been found, was a gregarious animal, and so differed in its habits from the ostrich. They appear to have frequented the swampy sea shores in enormous numbers, and from their footprints seem to have been capable of very rapid motion, and to have rivalled the ostrich in its power of running.

In New Zealand, recently, great light has been thrown on the subject of fossil Birds by many discoveries. The Dinornis was described by Professor Owen as a fossil species many years before it was found that that bird had been contemporaneous with man. The statements of the natives, if they are to be believed, prove that it has been seen; and their traditions go farther back than the Dinornis, and describe the gigantic Moa, a bird which must have rivalled in dimensions the original Brontozoon, and which one of our modern naturalists has ventured to suppose may still exist in some of the remote corners of the middle island of New Zealand.

I now proceed to describe the fossil history of the Echinoderms, respecting which we have much more information, although not of so important and interesting a kind as that relating to fossil Birds. The Echinoderms lived in the sea, and we may therefore expect that whatever portions of their bodies are capable of being preserved in a fossil condition will be found in abundance as fossils. We are therefore not surprised to find, that, in conjunction with the Crustaceans and the Mollusks, the Echino-

derms constitute a principal part of our fossil remains. The Echinoderms are well known to every person who has walked along the sea shore, and has examined fossils, by their general form. They were formerly placed amongst the radiate animals; but it is now generally agreed that they are worthy of a higher place in creation than that formerly assigned to them amongst the corals, and they are placed, accordingly, in most recent classifications, in a distinct sub-kingdom.

With respect to their geometrical symmetry they deviate so remarkably and so uniformly from the type of the corals, that we might naturally expect that they belonged to a different group, or perhaps to a different sub-kingdom in nature. The essential symmetry of the sea nettles and the corals is that of relation to an axis produced, and round it a right cylinder described, the transverse section of which shows the symmetry of the animal. A hasty examination of the Echinoderms would lead us to the conclusion that they also are radiate animals, arranged mostly with reference to five radiating planes. But a little further examination of these animals will always show that one of these five planes may be distinguished from the others, and that it is entitled to be considered as the plane of symmetry. We always find in the recent Echinoderms, and in many of the fossil, evident traces that some one of these five rays is entitled to be considered as antero-posterior, and that therefore the other two or lateral pairs may be described as the right or the left hand. This is indicated in a thousand ways which it would be tedious to enumerate, In every case where the mouth and the anus of these animals are distinct, the plane along which these apertures are situated indicates an antero-posterior plane of symmetry. The

ovarian or madreporiform plate, which is supposed to be connected with the reproduction of the animals, is also placed in a situation distinct from the mouth; and the radiating plane joining these two points gives us the plane of symmetry. There is therefore in these animals a deviation from the perfect type of symmetry round a line, which leads us to suspect that they are not true Radiata.

Therefore they have been promoted by modern naturalists to a higher order, the *Echinozoa*, in which a symmetrical arrangement right and left handed with reference to a plane of division is a predominant character.

They are divided by geologists into the following Orders:—

SUBKINGDOM ECHINOZOA.

ORDERS.	*Characters.*
I. CRINOIDA, (κρινωδῆ).	Body spheroidal, pyriform or depressed, surrounded by a frame-work of calcareous plates, from the upper border of which the calcareous supports of the arms proceed; mouth always superior, central; arms distinct and lateral; generally, but not always, mounted on a flexible stalk.
II. ASTEROIDA, (ἀστεροειδῆ).	Body divided into branches, generally five in number; skin covered with hard calcareous plates, often spinous, not united at their borders; mouth inferior and central; anus, when it exists, superior.
III. ECHINOIDA, (ἐχινωδῆ).	Solid spheroidal shell, composed of plates united at the borders, and covered with spines, provided with a ball and socket joint; mouth and anus distinct.
IV. HOLOTHURIA, (ὁλοθούρια).	Skin leathery; animal in the form of a cylindrical sack; divided into five segments by lines of retractile tubes.

1. Crinoids.—The Crinoids, or Sea Lilies, have generally branching arms, and are fixed to the ground by means of a stalk, composed of jointed segments. These segments are frequently found separated from each other, and are well known from the earliest times of geology, as Screwstones, Trochites, Entrochi, and by other names.

They are usually divided into the Crinoids proper, the Cystids, and the Blastoids; for details respecting which I must refer to larger treatises than this Manual.

I have selected as types of the several forms of the Crinoids the following species:—

Encrinus liliiformis, of the Muschelkalk;

Pentacrinus Briareus, of the Lias;

Marsupites ornatus, of the Chalk.

The *Encrinus liliiformis*, of the Muschelkalk, is represented in Fig. 42. It possesses an enlarged, short, concave calyx, composed of five basal segments, on which rest the first five brachial segments, each followed by two others which are free, and carry two arms making altogether ten arms, formed of double rows of alternating rings, and which are sometimes regarded as twenty arms. The stem is formed of round vertebræ, pierced in the centre with a round hole, and provided on the articulating surfaces with radiating striæ or ribs.

FIG. 42.

ENCRINUS LILIIFORMIS.
Muschelkalk, Germany.

The Pentacrinites, of which *Pentacrinus Briareus* (Fig. 43), is the type, have a thickened short calyx,

Fig. 43.

PENTACRINUS BRIAREUS.
Lias.

composed of a small number of segments; a pentagonal stem, adorned with whorled branchlets, and

formed of vertebræ, whose articulating surfaces have a radiated structure; and they are provided with long and branching arms.

The Pentacrinites are still represented by a single living species, *Pentacrinus caput Medusæ*. The fossil species belong chiefly to the Liassic epoch.

The *Marsupites ornatus* (Fig. 44), of the Chalk, illustrates a remarkable form of Echinozoon, which resembles in all respects the Crinoids, except that it is not and never was provided with a stem. It seems to have been rolled lazily to and fro, by the influence of the waves, at the bottom of the sea, and to have been anchored in its place by the action of gravity alone.

FIG 44.

MARSUPITES ORNATUS.
Chalk.

II. Asteroids.—The Sea Stars are so well known, that they need no description beyond that of their characters already given.

They are subdivided into Asterids, Ophiurids, and Edrioasterids, which are here regarded as sub-orders.

I have selected to illustrate them two remarkable species:—

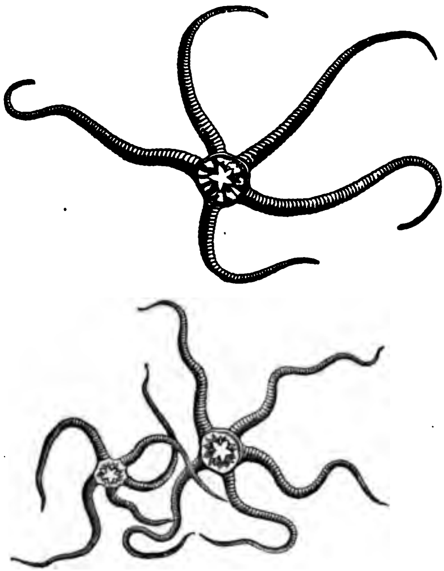
Ophioderma Egertoni, of the Lias;

Asterias arenicolus, of the Calcareous Grit.

The *Ophioderma Egertoni*, formerly called Ophiura (Fig. 45), is distinguished from the other Ophiuridæ by having four genital apertures between each pair

of arms, while the others possess only two such slits; the disk is granulated, and the arms exhibit on their margins papillæ, or fine short spines; the oral slits are surrounded by strong papillæ. This remarkable genus, which contains several living

Fig. 45.



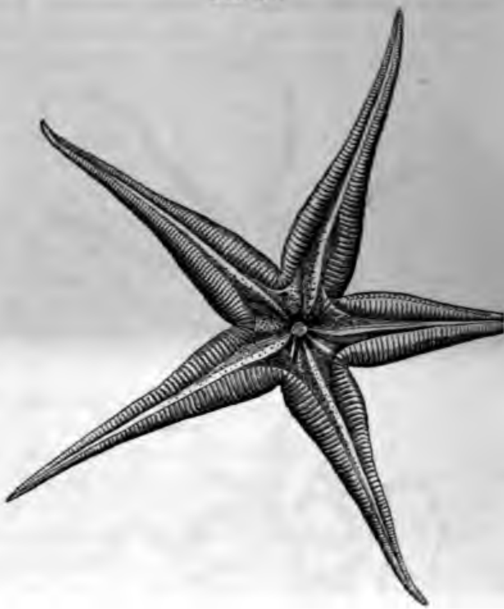
OPHIODERMA EGERTONI.
Lias, Lyme Regis.

species, has hitherto been found fossil only in the Lias.

The *Asterias arenicolus* (Fig. 46), from the calcareous grit of Yorkshire, forms a regular star, the long arms of which are provided on each side with

a double row of large plates; the inferior carry pointed scales, and the superior only granules; the dorsal surface between these row of plates is co-

FIG. 46.



ASTERIAS ARENICOLUS.
Calcareous Grit, Yorkshire.

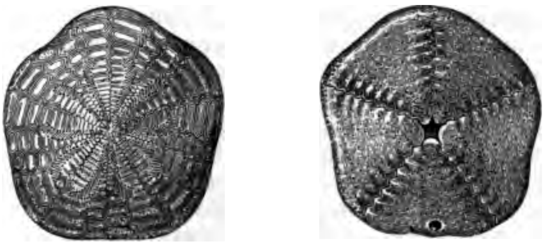
vered with small appendages; the anus is wanting.

III. Echinoids.—The Echinoids, or Sea Eggs, are as well known as the Sea Stars, and constitute the well-known type of the Echinozoa.

I have selected as a fossil specimen the *Clypeaster altus* (Fig. 47), found abundantly at Malta, near the pyramids in Egypt, and in general characteristic of the Cretaceous and Post-cretaceous deposits of the Mediterranean coasts.

It has been remarked by naturalists who have studied the developement of the Echinozoa, that

FIG. 47.



CLYPEASTER ALTUS.
Older Tertiary, Egypt.

when young they undergo metamorphoses like the Crustaceans; and in the young condition many of the forms of the Echinoderms, which in the adult condition become free, are fixed by a pedestal on a stalk.

It is well known that, although there is no regular order of developement in the history of these creatures on the globe,—although we cannot say that the Crinoids came before the Asteroids, or the Asteroids before the Echinoids,—yet on the whole, in the older periods of the earth's history, in the Palæozoic and Neozoic periods the sea lilies preponderated greatly over all the other forms, and the free swimming Echinoderms may be regarded as

modern when compared with the fixed Echinoderms. In the case, therefore, of these creatures we have the law developed which appears in several groups of the animal kingdom, though not universally true; that the older forms of life in the history of the group upon the globe correspond with the older forms of life of the individual. If we draw a curve representing the zoological importance of the Echinoderms in time, similar to Diagram No. II, p. 104, it will appear that they never attained a zoological importance of more than ten per cent. or more than one in ten of the coexisting creation. The curve of the Echinozoa differs totally from the curves of the Crustaceans, Fishes, Reptiles, and Mammals. These four great groups reached their maxima of developement, and then declined. The Echinoderms, on the contrary, appear to have reached several maxima—three maxima, and three minima; and they are at present to be regarded as occupying a low position in the creation with regard to zoological importance. This we shall find to be a fact that is repeated in several kinds of living creatures; and in our next Lecture, in speaking of the Mollusca, I shall call your attention to the remarkable curves of zoological importance formed by the four groups of Mollusca, which we shall find to differ in many important respects from that of the Echinoderms.

The class of animals which the Echinoderms most nearly resemble in the law of their developement in time is that containing the corals. We find that the corals, from an equally early period, retained somewhat of the same degree of relative importance throughout the whole of their existence down to the present time, and nowhere show any remarkable tendency to reach a maximum

and then decline. This tendency in other creatures may possibly be connected with the very fact of their being of a higher organization. It is quite possible that creatures of a higher organization are capable, when circumstances admit, of taking possession of a portion of the globe, and of holding it against all comers, in a manner which inferior creatures are not capable of.

Remains of Echinoderms have been found in all the principal fossil marine deposits from those of the Lower Silurian to the present day. No class of invertebrate animals appears to have been better represented during past epochs, while in the seas of our own time these animals abound, alike in polar, temperate, and tropical latitudes.

Of the Orders into which they are divided, one is almost wholly recent, the scant traces of fossil Holothurids which have been recorded being either doubtful or post-tertiary. On the other hand, the small sub-order of Edrio-asterids includes only extinct forms. A third Order, the Crinoids, with but few living forms, may be said to have attained its maximum in former (especially in Palæozoic) periods, during which it was represented by many highly diversified Genera and Families, now, for the most part, extinct. The reverse is probably true of the Asterids and Ophiurids. Lastly, the Order of Echinoids, represented in Palæozoic rocks by a peculiar Family, offers a rich display both of Secondary and Tertiary forms, and in existing seas is still, though on a less varied scale, abundantly illustrated.

The Orders most interesting to the palæontologist are the Crinoids and the Echinoids, because represented at all epochs, and presenting very definite

relations to time. The hard parts, in these Orders, are eminently susceptible of preservation. The fossil Star-fishes are less varied, less frequent, in general not so well preserved, and therefore less worthy of palæontological notice.

We obtain the most general view of the relations of Echinoderms to time by contrasting the Palæozoic with Neozoic forms, whether these be recent or extinct. The Palæchinidæ* among Sea Urchins, and among Crinoids the Cystids, are exclusively Palæozoic, as are also the tesselate Crinoids and the Blastoids, with the exception in each case of a single genus.† No other Echinoderms are found in Palæozoic rocks, save the Edrio-asterids, and a few genera of Asterids.

To Neozoic and Ontozoic periods belong:—

1. The articulate Crinoids, and of tesselate Crinoids, the genus Marsupites. Also one genus (Phyllocrinus) of Blastoids.
2. Most genera of Asterids.
3. All the Ophiurids.
4. All the Echinoids, except the Palæchinidæ.
5. All the Holothurids.

Thus the Order Echinoids, which first gave a name to the Class, including the longest known, and (according to generally received views) the most typical Echinoderms, may be said also best to represent the entire group in its palæontological relations. For this order has at once its special Palæozoic Family, its well preserved and characteristic remains in Neozoic rocks, and, lastly, a sufficient diversity of types in the recent ocean.

* These have three or more longitudinal series of plates in each interambulacrum. The intercalated plates are therefore hexagonal. Such plates do not occur in other Echinoids.

† Both these exceptional genera were Cretaceous forms.

I am indebted to Professor Greene for the account here given of the history of the fossil Echinoderms.

ORDER I.—CRINOIDS.

Sub-Order A.—Crinoids Proper.

1. Tessellata.
2. Articulata.

Palæozoic—All the Tessellata, except *Marsupites; no other Families. Silurian genera are more numerous than Devonian; Devonian than Carboniferous; the number of species is in reverse order.

Cyathocrinoids range through all the Palæozoic rocks. This Family vastly preponderates in number of genera and species. Cyathocrinus itself (also Silurian, Devonian, and Carboniferous) is the only Permian Crinoid known.

Haplocrinoids and *Cupressocrinus are only known as Devonian. *Anthocrinus is exclusively Upper Silurian. *Eucalyptocrinus is Silurian; it is also doubtfully Devonian.*

Triassic—include only Encrinidæ proper (Encrinus, Calathocrinus, and Flabellocrinus), peculiar to this formation, and Pentacrinus, which ranges through all later periods to the present.

Jurassic—All the Families of articulate Crinoids (except Encrinidæ) occur here; both genera and species are far more numerous than at later periods.

Cretaceous—All the Jurassic Families, some very scantily. Also Marsupites, the only tesselate Crinoid which survived the Palæozoic epoch, and Saccocoma, for which J. Müller constituted the primary group of Crinoidea costata.†

Tertiary—All the Jurassic Families, except Eugeniacrinidæ, which died out in the Chalk. Scarcely more than a dozen Tertiary Crinoid species are known; nearly half of these belong to Pentacrinus proper. Conocrinus and Cœnocrinus are characteristic of this period.

Sub-Order B.—Blastoids.

(About six described Genera.)

All Palæozoic, except one species of Phyllocrinus from the Greensand. This, however, is a very doubtful form. The genus Zygocrinus is also doubtful.

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* Those marked (*) are the sole types of their Families.

† Both genera peculiar to this formation.

Most of the species belong to the genus Pentremites, which has 3 Upper Silurian, 6 Devonian, and nearly 40 Carboniferous forms.

Codonaster is also Carboniferous, but has 2 Devonian species.

Eleutherocrinus and Elæacrinus (1 species each) are exclusively Devonian.

Thus this group preponderates in the Carboniferous Limestone, and has no Lower Silurian forms, in both respects contrasting with the next group.

SUB-ORDER C.—CYSTIDS.

All the species Palæozoic (none Permian).

To the Carboniferous Limestone belong Zygocrinus (1 doubtful species, which is perhaps referrible to Crinoidea tesselata), and 3 species of Cryptocrinus, removed by Austin to a separate genus, Sycocrinus.

The only Devonian species is the Echino-sphærites tesselatus of Verneuil, which seems doubtful.

All other Cystids (about 25 genera and 70 species) are Silurian. Lower Silurian forms are most numerous. Several very interesting ones are described by Billings in his third Canadian Decade.

ORDER II.—ASTEROIDS.

SUB-ORDER A.—ASTERIDS.

Well represented by recent forms, even more so than the Ophiurids.

Many Palæozoic forms (thus differing from Ophiurids). Some of these can hardly be distinguished from existing species; others have been referred to distinct genera; (e.g. Palæaster, Ag.), of which about 10 are exclusively Palæozoic. It is not certain that any Palæozoic Asterids are generically identical with Secondary forms.

Of Triassic Asterids, there is but one recorded species, its nature obscure.

In Jurassic rocks occur Luidia, Chætaster and Asteracanthion, which are likewise recent; the last is also Tertiary. Astropecten and Goniaster are also Jurassic; they range through Chalk and Tertiary to Ontozoic period. Tropidaster and Pleuraster are exclusively Jurassic.

There are many Cretaceous Asterids, most of which belong to existing genera, e. g. Goniodiscus and Astrogonium. Arthraster is peculiar to the Chalk.

Tertiary Star-fishes resemble the Cretaceous and recent forms.

Cœlaster, a confusing genus, is said to range from Palæozoic rocks to Chalk. Forbes* doubts if it be an Asterid at all.

SUB-ORDER B.—OPHIURIDS.

Well represented in existing seas.

None proved to be Palæozoic (some Silurian Star-fishes, e. g. Protaster look like Ophiurids, but are really Asterids). A like simulation of form occurs in the recent genus Brissinga.

The Family Euryalidæ has no extinct representatives.

Most fossil Ophiurids have been found in Secondary rocks.

There are but two or three described Tertiary forms: one belonging to Geocoma, a Jurassic genus; another to Ophiura, which ranges from Lias to present day.

Ophycoma (not Ophiocoma, a recent genus),
Palæocoma (not Palæocoma, *Salter*, an Asterid),
} (genera founded by D'Orbigny), are said to be exclusively Cretaceous.

Aspidura and Acroura (both genera of Agassiz, the latter including Aplocoma, D'Orbigny) are "Muschelkalk." Forms resembling them, but probably Ophiuræ, range through the Oolite up to the Chalk. All these require revision.

Ophiurella and Geocoma are "Solenhofen" forms.

Ophioderma is Liassic and recent.

All the above genera mentioned in this Sub-Order, save when the contrary is stated, are extinct. No other fossil genera are known.

Forbes, in "Geological Proceedings," 1843, gave a list of the fossil Ophiurids then known. Few others have since been described. It is probable that many Tertiary forms both in this Order and the Asterids will soon be brought to light.

SUB-ORDER C.—EDRIO-ASTERIDS, *Billings.*

(Vid. Third Canadian Decade, pp. 82–5, 1858.)

But one well-marked genus, Agelacrinus, *Vanuxem* (now extended to include Hemicystites, Hall, and Haplocystites, F. Rœmer).

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* His paper on Fossil Asteridea (in "Mem. Geol. Survey," vol. ii.) gives a good list of species. See also some useful papers by Salter, in "Ann. Nat. Hist.," Nov. 1857, and Dec. 1861 (the last corrects the first).

An excellent account of this Sub-Order is given by Chapman, in "Ann. Nat. Hist.," September, 1860, p. 157. He objects to Billings' name, and would call the Order "Thyroidea."

By Forbes it was placed with the Cystids. (See his paper in "Geol. Memoirs.")

Of Agelacrinus, 10 species have been described, viz. :—

Lower Silurian, ...	6.
Upper Silurian, ...	1.
Devonian, ...	2.
Carboniferous, ...	1.

Agelacrinus has an inter-ambulacral orifice resembling the "pyramid" of the Cystids, but differs from these Echinoderms, in,—

a.—Having no stalk. We are not sure that it was permanently fixed.

b.—Having some (or all) of its inter-ambulacral plates imbricating.

c.—Having its mouth (not yet seen) probably placed as in Star-fishes, that is, turned downwards. If this be so, it decidedly was no Crinoid. No orifice has been certainly seen in the centre of the exposed surface from which the ambulacra diverge.

d.—Having ambulacral pores (in all good specimens) between the sutures of the plates, 2 between every 2 successive plates of each series.

e.—Having a much more depressed form of body.

Echinocystites, Wy. Thomson ("Edin. New. Phil. Journ.," January, 1861), is very near Agelacrinus, but has spines. The ambulacra were somewhat different (but nowise Cystidean), and the body more globular.

Palæodiscus should probably follow, but I think it very obscure.

ORDER III.—ECHINOIDS.

Palæozoic forms all belong to one Family, Palæchinidæ, which does not survive this epoch.

Triassic forms are all Cidaridæ, a Family found in most succeeding deposits, and at the present day. This is true of Cidaris itself, which includes several Triassic species. I know of no Echinoid genus peculiar to the Trias. Hypodiadema, Rhabdocidaris, and Hemi-cidaris are also Jurassic and Cretaceous. The last is likewise Tertiary.

Jurassic Urchins. No Spatangidæ or Clypeastridæ proper. Dysasteridæ better represented than in Chalk; Cassidulidæ not so well; the other Families about equally well.*

Cretaceous Urchins include all the Neozoic and recent Families, and all of these are well represented. Salenidæ, Dysasteridæ, and Galeritidæ here die out. Spatangidæ and Clypeastroidæ now first appear. Cidaridæ better represented than in Tertiary, not so well as in Jurassic strata.†

Tertiary Urchins. All the recent Families occur; none others. Spatangidæ particularly well represented, better than in Cretaceous or recent seas. Cidaridæ and Clypeastroidæ about as well represented as at present. Cassidulidæ better; not so well as in Chalk.‡

Taking a broad and general view of the history of the Echinoderms, we cannot say that the Echinozoic type of structure has progressed or retrogressed, or that it has either acquired a greater or a less zoological importance numerically than it had formerly. It is quite true that, reasoning from the developement of the individual from its younger to its adult stages of life, we have reason to say that the Echinoderms have passed from less to more developed forms. But when we consider the extraordinary elegance and perfection of the ancient stone lilies, we must be disposed to regard it as a mere fancy of the naturalist that there is any natural connexion between the earlier appearance of the Crinoids and the later appearance of free forms, rather than say that one form appears to have been as perfect as the other, both of them being intended, no doubt, for the conditions in which they were placed. Such slender evidence as is afforded by these fossil Echinoderms can never construct a

* Dysasteridæ is here the most notable family.

† Cassidulidæ has here its maximum. Galeritidæ and Salenidæ somewhat better represented than in Jurassic.

‡ Spatangidæ prevail over other Tertiary Urchins. Clypeastroidæ better developed than in Chalk, not quite so well as in recent seas.

law of nature, which must rest upon much more precise and accurate evidence than such vague analogies as these.

The pleasure to be derived from the study of the different forms of these and other creatures at different periods of the earth's history cannot be overrated; and I am certain that we should find greater pleasure and knowledge if we pursued the study of them with less of theories to account for them, and rested more content, as we do in other branches of science, with the knowledge of the positive facts of nature which science teaches us. The natural tendency of all sciences, from which geology is not exempt, is to pass through a poetic or mystic stage at the commencement of its existence. It may be described, fairly enough, as somewhat analogous to the stages of developement which the animals themselves are supposed to have gone through.

In the exacter sciences it is now universally recognised that the true type of a science is that which rests perfectly contented with what, to the young beginner, appears a very barren result, namely, the mere accumulation, and grouping together of important facts. If we are contented with such a study of the sciences of geology and palæontology, they afford us the greatest possible variety of such facts; and I have no doubt that, in course of time, laws and some kind of order will begin to appear from those facts. But at present they point towards opposite directions; the inferences to be derived from one group of animals appear to be contradicted by those obtained from others; and it is the safer course at present, I believe, to remain content with collecting these facts, and so build up the frame-work of geology as a positive science.

LECTURE XIII.

THE MOLLUSKS—SYMMETRY—CEPHALOPODS—PTEROPODS—GASTEROPODS—ACEPHALS—BRACHIOPODS—POLYZOANS.

I HAVE to ask your attention in the present Lecture to the important and to geologists the most interesting of all the groups of the Animal Kingdom—the Mollusks. Being inhabitants of the sea, and more abundant than the Crustaceans or Fishes, or other marine animals, it is evident that they are capable of affording to the geologist most valuable and important information. Many of the Mollusks are provided also with calcareous shells, which are therefore capable of being preserved in pure limestone unaltered, and even in slates and sandstones as casts and moulds. It is therefore evident that they are capable of furnishing, and in point of fact we find that they do furnish, most valuable and important information to the palæontologist and the geologist.

The Mollusks form one of the great classes of the Animal Kingdom originally established by Cuvier, who placed them in his scale of classification above the Articulate animals. But it is now generally considered that, although some of the Mollusks excel in intelligence many of the Articulate orders,

this is not a sufficient ground for placing them above them. The Articulate or Annulose class are now generally placed next to the Vertebrate, and the Mollusks occupy the third class in the Animal Kingdom. We divide the Mollusks into the following groups :—

CLASS MOLLUSCA.

ORDERS.

I. CEPHALOPODS—(τὰ περὶ τῆς κεφαλῆς πόδας ἔχοντα).
II. PTEROPODS—(τὰ τοὺς πόδας πτερώτους ἔχοντα.)
III. GASTEROPODS—(τὰ τῇ γαστρὶ ἀντὶ τῶν ποδῶν χρώμενα).
IV. ACEPHALS—(ἀκέφαλα).
V. BRACHIOPODS—(τὰ τοῖς βραχίοις ἀντὶ τῶν ποδῶν χρώμενα).
VI. POLYZOANS—(τὰ πολλὰ ζῷα τῆς μιᾶς ζωῆς μετεχόμενα).

This classification is especially suited to the purposes of the geologist. There are other groups of the Mollusks, which, as they possess no shells, and are essentially composed of soft parts, can never become fossil, and therefore respecting their former history we can have no knowledge. The Orders named occur abundantly in a fossil condition, with the exception of the Pteropods, which, although they are common in some groups of rocks, are rare in others.

The sixth Order, or Polyzoa, are the lowest in organization of the class, and resemble so closely, in their appearance, when preserved as fossils, many of the coralline forms, that they have by most writers on geology and palæontology until recently been confounded with them. They are now known to constitute a much higher group in the scale of creation than the corals, and yet to be the lowest in the group of

Mollusks. They resemble the corals in one remarkable peculiarity—they are not individuals, but are composed of a number of individuals living together in a system, in which the nutriment and food absorbed by each individual goes to sustain the whole mass. This community of food indicates a lower type of structure than the individuality which characterizes the higher Mollusks, and for this reason alone we are justified in placing the Polyzoa at the bottom of that group. They appeared at the very earliest stage of the earth's history, in which they are represented by Oldhamia and Graptolites, and have continued ever since.

The Cephalopods afford a remarkable example of the geometrical symmetry to which many groups of the Animal Kingdom are subject. Their symmetry is that of relation to a plane, and to a line per pendicular to that plane. If we imagine a perpendicular to be drawn through a plane, and round its intersection on the plane a spiral to be formed, and the animal organism to develope itself along that spiral, we have the essential characteristics of the highest Order of the Cephalopods. The nucleus of the shell is the intersection of the line of symmetry to which the animal is related with the plane; and as the young animal grows, he describes a spiral turning round this point.

To pass from the Cephalopods to the Gasteropods, we have simply to imagine the symmetry to be different. Take the axis of symmetry of the Cephalopods, and draw up the head of the spiral along the line perpendicularly to the plane, so as to convert it into a helix, and by this process we produce what is so well known, the helicoid form of the Gasteropodous Mollusk. The symmetry of the Gas-

teropods is that of a helix described upon a right cone—not a helix described upon a cylinder, which is characteristic of the geometrical symmetry that regulates the growth of plants; and it is a remarkable fact, that in some of the fossil forms of the Cephalopods, this spiral form of symmetry on a plane, which is characteristic of the group, gives way to the inferior form of symmetry in a helix, as is well shown in Fig. 48.

FIG. 48.

TURRILITES TUBERCULATUS.

I. **Cephalopods.**—These Mollusks are formed of a sack-shaped body, with a large head, separated from it by a distinct neck; and furnished with arms, used for prehension and locomotion, arranged in a whorl round the mouth, which is placed in a central funnel. The organs of sense, and especially the eyes, are almost as perfect as those of the Vertebrate animals. The shell is sometimes external, and sometimes internal, and is symmetrical with reference to a plane, and generally chambered, with a siphon connecting the different chambers.

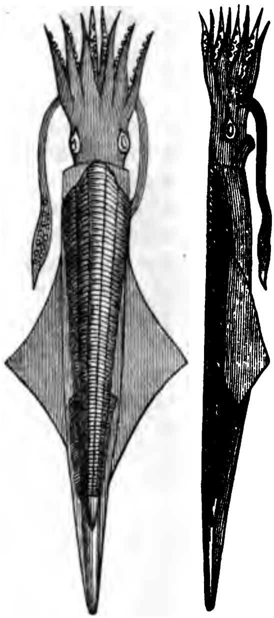
The Cephalopods are divided into two great groups or Sub-Orders:—

SUB-ORDERS.	*Characters.*
1. *Cephalopoda acetabulifera.* .	**Arms furnished with suckers; shell none, or internal, except in one genus, in which it is external, but not chambered.**

2. *Cephalopoda tentaculifera.* . **Arms without suckers; shell external, and chambered.**

In Fig. 49, I have given D'Orbigny's restoration

FIG. 49.



RESTORED BELEMNITE.

of the true form of the most celebrated of the Belemnites, or fossil Acetabuliferous Cephalopods. These ancient cuttle fish sometimes attained the length of four feet, and, provided as they were with prehensile hooks on their long arms, and with a formidable parrot-like bill, they must have proved dangerous antagonists even to the well protected fishes that lived in the same seas with them. They were also furnished with the well-known ink bag, with which they could darken the water in their neighbourhood, and elude the pursuit of their enemies. There is one remarkable difference between the iodern and ancient cuttle fishes that must be riefly noticed. It is well known that the internal one of a recent cuttle fish floats in water; that one, therefore, in the interior of the animal acts es-entially as a float; and the cuttle fish, provided rith this light and spongy bone, has part of the

weight of his body sustained by the floating power of his internal skeleton. From the habits of the animal, which feeds at the bottom of the sea with the head down and the body raised in the water, considerable assistance must be given to him by this bone in supporting the weight of the body. The bone is made light by air cells introduced between its plates, so that it becomes specifically lighter than the water. But in the Belemnites, or Cephalopods with internal bones, of the ancient seas, we find a totally different provision. Of the carbonate of lime, of which these bones are composed, there are two forms known to mineralogists, namely, Calcite and Aragonite. These differ in many respects, but in none more strongly than in their relative specific gravities. The Aragonite is much heavier than the Calcite; and both are much heavier than the bone of the cuttle fish. Now, we find without a single exception that the fossil internal skeleton of all the ancient cuttle fishes was formed of Aragonite, so as to give the densest and heaviest bony structure that the nature of the case admitted of. We are therefore led necessarily to the conclusion that the habits of life of the animal must have been the reverse of those of the modern cuttle fishes; that the bony internal skeleton was intended in those Mollusks to act as a sinker, and not as a float; that the animal floated freely in the water, the whole body probably having a specific gravity somewhat near that of the water round him, and that the heavy weight which he carried as an internal skeleton kept the head up. Dr. Buckland and other writers have supposed from this peculiarity that the habit of this Mollusk was to seize its prey from below; and from the size, and

probable voracity of some of these creatures, we may readily believe that they may have been capable of attacking from below small fishes floating in the water, fastening their arms in them, and we find that many of these arms, which are preserved in the lithographic stone of Solenhofen, are provided with hooks, so that they were capable of seizing their prey in the manner described.

The Tentaculiferous Cephalopods are known to us in modern times by means of a single genus only, the Nautilus, which has existed from the earliest times, and still lives in the Pacific Ocean.

The internal structure of the shell is well seen in Fig. 50, which represents a section of the shell

Fig. 50.

NAUTILUS POMPILIUS.

of *Nautilus pompilius*. A shell of this description consists of a series of chambers cut off from each other, the animal living in the outer cham-

ber; and the continuity is kept up from chan
to chamber by means of a siphon, which i
tube protected for a short distance from each
tition by a calcareous cylinder, and filled up a
the intervening spaces by a membranous and c
laginous tube. The animal lives in the outer ch
ber; and, with regard to his position, it is w
while to remember that he lies upon his face,
his back to his shell; the belly is placed upon
outer, and the back upon the inner surface of
chamber. In most books you will find one sur
spoken of as the dorsal, and the other as the
tral aspect of the Cephalopod. We ought to
them the external and the internal, which would le
no doubt as to the true character of the terms u
because in the recent Nautilus—and we have no
son to suppose that the extinct ones differed from i
the terms dorsal and ventral ought to be revers
The animal is so placed in the shell as if a per
were placed lying on his face on the table, with
feet rolled up spirally backwards. The distinctio
one of importance, because we divide all these
phalopoda into three great divisions, according to
position of the siphon, namely—those with a cent
siphon, those with an internal, and those with an
ternal siphon. If you use the terms "ventral" a
"dorsal," you must use them of course in the acc
rate sense. I shall have no time in this course
Lectures to go into details as to the many forms
Cephalopods to be found, nor to give you any accou
of the disquisitions, which have been great a
varied, as to the functions of this mysterious sipho
which is the part of the shell which has caused t
greatest perplexity to naturalists in the examinati
of extinct Cephalopods.

In order to show the variety of extinct forms of Tentaculiferous Cephalopods, I have figured five species, taking them in the order of geological developement.

In Fig. 51, is represented the *Orthoceras fusiforme* of the Carboniferous Limestone of the county of Kildare. The Orthoceratites, or straight-chambered shells, are characteristic of the Palæozoic epoch, and may be described as Nautilids unrolled. They resemble the Nautilus in the simple form of the chambers, and in the central position of the siphon. Many of them attained considerable dimensions, extending to the length of ten or eleven feet. The largest species hitherto found were met with in the Carboniferous Limestone of Comber, county of Down, and are described by Sowerby under the name of *Orthoceras giganteum*, now generally called *Actinoceras giganteum*, as it is well distinguished from Orthoceras by the very complicated structure of its siphon.

Fig. 51.

ORTHOCERAS FUSIFORME.

The *Nautilus* possesses a central siphon, and is rolled upon itself symmetrically, in such a manner that the earlier turns of the shell are more or less hidden by those formed afterwards. Fig. 52 represents a Neozoic Nautilus, from the Oxford clay of Calvados; it is called the *Nautilus giganteus*, and may be regarded as a typical specimen of the Mesozoic Nautilids.

FIG. 52.

AUTILUS GIGANTEUS.
Oxford Clay.

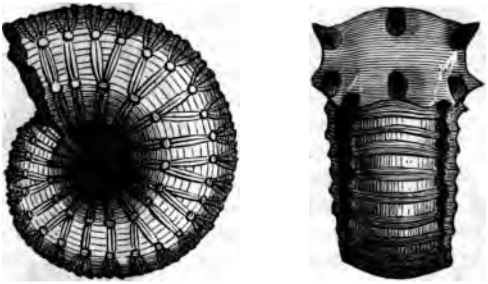
The Ammonites form a remarkable group of Cephalopods, characterized by an external siphon, and chambers of complicated, often foliated pattern. This foliated structure gives a remarkable character to the intersection of the chamber partitions with the shell, and must have added greatly to the strength of the shell, which was always delicate and often very beautiful; for the mother of pearl surface appears to have been exposed without any cortical integument.

Fig. 53 represents *Ammonites Henleyi*, a characteristic shell, from the Middle Lias.

It is well worthy of remark that Ammonites were found by Sir Leopold M'Clintock in Prince Patrick's Island, in Lat. 76° N. At the time these animals lived in the Arctic seas, it is incredible that any organic life could have existed at the equator, as the temperature there must then have been sufficient to coagulate albumen.

The Ammonites made their first appearance to-

Fig. 53



AMMONITES HENLEYI.
Middle Lias.

wards the end of the Triassic period; they abounded in the Jurassic and Cretaceous periods, and disappeared before the Tertiary beds were deposited. They are therefore essentially Mesozoic fossils, and are the natural successors of the Goniatites of the Palæozoic age, which differed in many respects from the contemporaneous Orthoceratites and Nautilids.

The later Neozoic forms of Cephalopods differed in many respects from the Mesozoic forms. In illustration of the difference, I have figured the *Ancyloceras gigas*, Fig. 54, of the Lower Greensand formation, and the *Turrilites tuberculatus*, Fig. 48, p. 304, of the Upper Greensand.

The former of these fossils may be regarded as an Ammonite partially unrolled, and the latter as an Ammonite endowed with the form and peculiar symmetry of a Gasteropod.

From an inspection of the curve of zoological importance of the Cephalopods, Diagram IV., p. 312, we find results quite different from those tabulated in

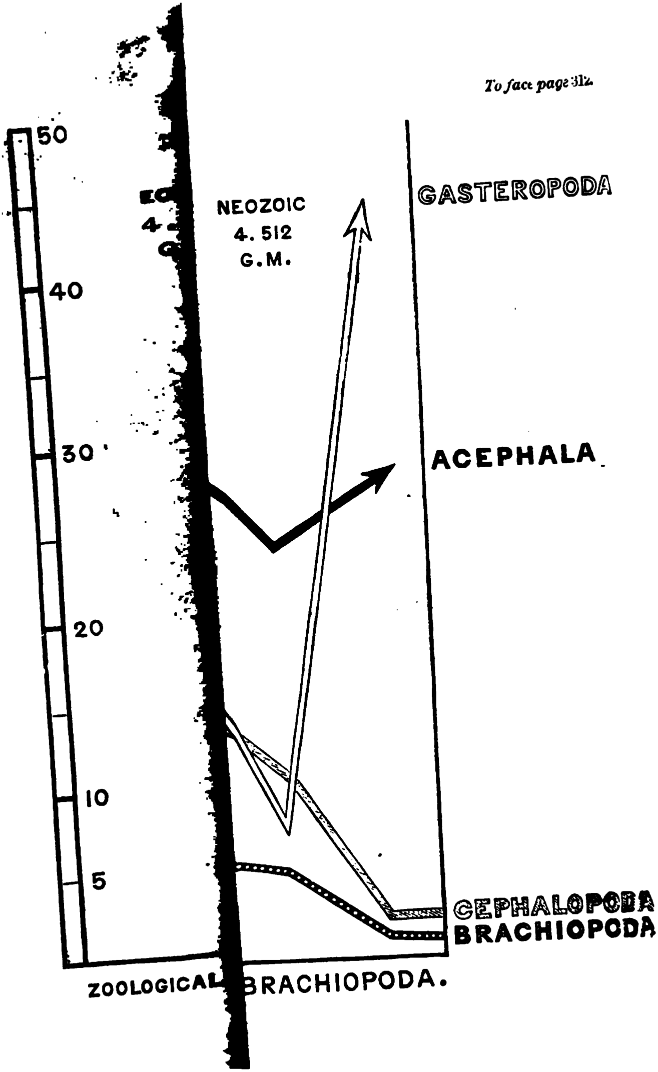
Fig. 54.

Ancyloceras gigas.

Diagram II., p. 104, for the Crustaceans, Fishes, Reptiles, and Mammals. Throughout the Lower and Upper Silurian periods, the Cephalopods increased slowly in importance, and at length attained a maximum of developement, which maximum was about twelve per cent. of the coexisting creation. After the period of the Upper Silurian they declined slowly, but at the close of the Palæozoic period with greater and increasing rapidity, until they reached a minimum in the Permian period, and rose suddenly again in the Neozoic period till they became sixteen per cent. of the existing creation, thus possessing a zoological importance greater than they had ever enjoyed before; and from that time, which occurred in the Oolitic period, to the present, they have rapidly declined, and may now be regarded as being at a minimum. Here therefore you will observe the law of developement of the Cephalopods to be the following, viz., that they increase gradually to a maximum, then decline again to a minimum; increase again, and finally attain a second minimum; so that there are two maxima and two minima.

It was this group of fossils that first suggested to the late Professor Forbes his idea of referring the whole history of creation on the globe to what he denominated two poles of creation—the Palæo-

To face page 312.



zoic and the Neozoic poles; and if this law were found to prevail throughout the whole of the Animal Kingdom, it would be a most attractive theory.

The following classification of the Cephalopods, recent and fossil, is borrowed from Mr. Woodward's excellent Manual of the Mollusks:—

ORDER I. DIBRANCHIATA (= ACETABULIFERA).

Animal swimming, naked; *head* distinct; *eyes* sessile, prominent; *mandibles* horny; *arms* eight or ten, provided with suckers; *body* round or elongated, usually with a pair of fins; *branchiæ* two, furnished with muscular ventricles; *ink gland* always present; *parietes* of the *funnel* entire; *shell* internal (except in Argonauta), horny or shelly, with or without air chambers.

This Order is divided into two sections:—

SECT. I. OCTOPODS. . . . *Arms* eight, suckers sessile; *eyes* fixed, incapable of rotation; *body* united to the head by a broad cervical band; *branchial chamber* divided longitudinally by a muscular partition; *oviduct* double, no distinct nidamental gland; *shell* external and one-celled, or internal and rudimentary.

Families. 1. Argonautidæ.
2. Octopodidæ.

SECT. II. DECAPODS. . . *Arms* eight; *tentacles* two, elongated, cylindrical, with expanded ends; *suckers* pedunculated, armed with a horny ring; *mouth* surrounded by a buccal membrane, sometimes lobed, and furnished with suckers; *eyes* moveable in their orbits; *body* oblong or elongated, always provided with a pair of fins; *funnel* usually furnished with an internal valve; *oviduct* single; *nidamental gland* largely developed; *shell* internal, lodged loosely in the middle of the dorsal aspect of the mantle.

Families.—1. Teuthidæ.
2. Belemnitidæ.
3. Sepiadæ.
4. Spirulidæ.

ORDER II. TETRABRANCHIATA (= TENTACULIFERA).

Animal creeping, protected by an external shell; *head* retractile within the mantle; *eyes* pedunculated; *mandibles* calcareous; *arms* very numerous; *body* attached to the shell by adductor muscles, and by a continuous horny girdle; *branchiæ* four; *funnel* formed by the folding of a muscular lobe; *shell* external, many-celled, and siphuncled, the inner layers and septa nacreous, the outer layers porcellaneous.

This Order is divided into the following Families:—

1. *Nautilidæ.* . . . . *Body chamber* of shell, capacious; *aperture* simple; *sutures* simple; *siphuncle* central, or internal.

Genera.—1. Nautilus.
2. Lituites.
3. Trochoceras.
4. Clymenia.

2. *Orthoceratidæ.* . . . *Shell* straight, curved, or discoidal; *body chamber* small; *aperture* contracted, sometimes extremely narrow; *siphuncle* complicated.

Genera.—1. Orthoceras.
2. Gomphoceras.
3. Oncoceras.
4. Phragmoceras.
5. Cyrtoceras.
6. Gyroceras.
7. Ascoceras.

3. *Ammonitidæ.* . . . *Body chamber* of shell elongated; *aperture* guarded by processes, and closed by an operculum; *sutures* angulated or lobed, and foliated; *siphuncle* external.

Genera.—1. Goniatites.
2. Ceratites.
3. Ammonites.

Genera.—4. Crioceras.
5. Toxoceras.
6. Ancyloceras.
7. Scaphites.
8. Helicoceras.
9. Turrilites.
10. Hamites.
11. Ptychoceras.
12. Baculites.

The following analysis of the leading genera of the Tetrabranchiate Cephalopods, also copied from Mr. Woodward's Manual of the Mollusks, may prove of service to beginners.

The shell of the Tetrabranchiate is an extremely elongated cone, and it is either straight, or variously folded, or coiled:—

1.	In	Orthoceras	and	Baculites	it is	straight.
2.	„	Ascoceras	„	Ptychoceras	„	bent on itself.
3.	„	Cyrtoceras	„	Toxoceras	„	curved.
4.	„	Trochoceras	„	Turrilites	„	spiral.
5.	„	Gyroceras	„	Crioceras	„	discoidal.
6.	„	Lituites	„	Ancyloceras	„	discoidal and produced.
7.	„	Nautilus	„	Ammonites	„	involute.

II. Pteropods.—These Mollusks live in the open sea, away from any shelter, save that which may be supplied by floating seaweeds. In habits and appearance they resemble the fry of the ordinary sea snails, swimming by the aid of a pair of winged fins, from which they derive their name. It is very doubtful whether they should be considered as fossil; for several forms, such as Conularia, referred to the Pteropods by some geologists, are considered to be Cephalopods by others. Their shells are very fragile, and rarely drifted on shore, but are found in abundance in the sediment deposited at great depths. They have been identified as Ter-

tiary fossils, both in England and on the Continent of Europe.

III. Gasteropods.—The Gasteropods, or common univalve shells of our sea shores, are so well known, that I need not spend much time in describing them. I have already stated to you their geometrical symmetry, that of being rolled or developed along a helix traced upon a cone; and it is worthy of remark that, if we imagine ourselves placed in the position of the young animal in its shell growing forwards, if we look from the back of the animal forwards in the direction which he looks himself, the spiral is developed in a right-handed direction, like the motion of the hands of a clock; we sometimes indeed find shells forming a left-handed spiral, and many of these were formerly considered to be monstrosities, caused by transposition of the viscera. There is reason, however, to believe that they are not really so, but that this form of spiral is a persistent character of some shells.

The history of the Gasteropods on the globe is one of extreme interest, and capable of affording us great instruction. Their curve of zoological importance is shown in Diagram IV., p. 312.

The Gasteropods rose to a first maximum of fifteen per cent. in the Lower Silurian period, followed by a minimum, and attained in the Carboniferous period a second maximum, which declined in the Triassic period to a second minimum, which, however was greater than their former minimum; and they rose afterwards to a third maximum, which shows an increase upon the former ones, and a regular progression. The first, second, and third maxima show a gradual increase in the efforts made by them to

attain zoological importance. And, finally, during the Tertiary period the Gasteropods attained to forty-two per cent. of coexisting species, thus reaching a magnitude of zoological importance that is not equalled even by the great curves that I have already called your attention to, viz., those of Crustaceans, Fishes, Reptiles, and Mammals.

The important contrast between the life histories on the globe of the Cephalopods and Gasteropods appears to me to convey valuable instruction. No one disputes for a moment the absolute superiority of the Cephalopodous Mollusca to the Gasteropodous. It is therefore a case where we have no difficulties to meet with from a doubt as to which of the two groups is the higher in the scale of creation. And yet we find the remarkable result that the most perfect and highest developed forms —the Cephalopods—reached two maxima, one minimum, and are now disappearing. They have evidently not kept pace with the supposed progression of the world; and at the time when man is introduced—the culminating effort of the whole creation—we find the Cephalopods, which were the highest of their race, in the act of vanishing.

On the other hand, we find the Gasteropods—a type of the Mollusca below them in importance, but somewhat analogous to them in structure—attaining maximum after maximum in succession, in a gradually increasing progression, and at the present moment occuping a more important and higher position than they ever did before upon the globe.

IV. Acephals.—These are Mollusks provided with bivalve shells, that cover the right and left sides of the animal; their plane of symmetry is the plane of

separation of the valves, which are called the right and the left valve, respectively. In the next Order, that of the Brachiopods, the plane of symmetry is a plane perpendicular to the plane of separation of the valves, which are called the dorsal and the ventral valve. The Acephals are sometimes called Lamellibranchs, from the fact that their gills are arranged in plates approximately parallel to each other. These plates are placed under the lobes of the mantle that secretes the shelly covering. In the other Order of Mollusks, which is bivalve, the Brachiopods or Palliobranchs, the mantle itself is made to perform the office of gills.

The mantle of all these Mollusks is the organ that secretes the shell, and is capable of assimilating and depositing carbonate of lime. It performs in many respects, only in an inferior degree, the office which in higher animals is effected by the periosteum, that of secreting an internal bony skeleton, with this difference, that in the shell the skeleton secreted has no organic connexion, or a very trifling connexion, with the body, whereas in our internal skeleton the organic connexion continues as long as life exists, and death to the skeleton is followed immediately by the destruction of the soft parts that surround it; and it frequently becomes necessary to remove the dead bone, or "sequestrum," in order to preserve the neighbouring soft parts. The mantle which secretes the shell surrounds the Mollusk as with a bag; and the more highly organized Mollusks—the Cephalopods, the Gasteropods, and the Lamellibranchs—are provided with separate and distinct gills, by which they breathe and absorb the oxygen of the water. The Palliobranchs, on the contrary, derive their oxygen from the particles of air con-

tained in the surrounding water, by means of the mantle itself.

The Acephala are divided into the following Sub-Orders:—

SUB-ORDER.	*Characters.*
I. *Orthoconchs.*	Shell equivalve, or nearly so; with two adductor muscles (except the genus Tridacna).

These are subdivided into the

1. Orthoconchæ sinupalliatæ.
2. Orthoconchæ integropalliatæ.

The Sinupalliate Orthoconchs have the impression of the mantle on the shell, with a deep sinus or bay near the anal region; indicating the existence of a retractile siphon, and the habit of burying themselves, mouth downwards, in the mud.

The Integropalliate Orthoconchs possess an open mantle, short siphons, and the impression of their mantle on the shell is devoid of any flexure or sinus.

SUB-ORDER.	*Characters.*
II. *Pleuroconchs.*	Shell inequivalve; one adductor muscle.

The following list of Families may be found useful:—

ORDER—ACEPHALA.

SUB-ORDER I.—ORTHOCONCHÆ.

A. Orthoconchæ sinupalliatæ.

1. Veneridæ, 2. Mactridæ, 3. Tellinidæ, 4. Solenidæ, 5. Myacidæ, 6. Anatinidæ, 7. Gastrochænidæ, 8. Pholadidæ,	with siphons.

B. Orthoconchæ integropalliatæ.

1. Tridacnidæ, 2. Cardiadæ, 3. Lucinidæ, 4. Cycladidæ, 5. Cyprinidæ,	with siphons.
6. Mytilidæ, 7. Arcadæ, 8. Trigoniadæ, 9. Unionidæ,	without siphons.

SUB-ORDER II.—PLEUROCONCHÆ.

1. Chamidæ,	with siphon.
2. Ostræidæ, 3. Aviculidæ,	without siphons.

V. Brachiopods.—These are bivalve Mollusks, in which the valves are dorsal and ventral, and not right and left valves. The ventral valve is usually the largest, and often furnished with a foramen near the beak, through which passes the ligament that anchors the Mollusk to the rock. The shells are inequivalve, but symmetrical with reference to a plane perpendicular to the plane of separation of the valves. This is expressed by stating the shells to be equal-sided. The valves are provided with adductor and abductor muscles; and the greater part of the interior of the shell is occupied with branching arms, furnished with cilia, which cause a constant current to flow towards the mouth of the Mollusk, and from these arms the Order derives its name. The arms are sometimes supported by calcareous skeletons, arranged like loops or spirals, and which are preserved frequently in the fossil specimens.

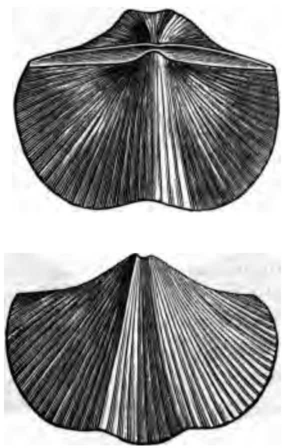
The following are the Families usually recognised:—

ORDER BRACHIOPODA.

FAMILIES.	*Characters.*
1. *Terebratulidæ.* . . .	*Shell* minutely punctate, usually round or oval, smooth or striated; ventral valve with a prominent beak, and two curved hinge-teeth; dorsal valve with a depressed umbo, a prominent cardinal process between the dental sockets, and a slender shelly hoop.
2. *Spiriferidæ.*	*Shell* furnished internally with two calcareous spiral processes directed outwards towards the sides of the shell, and intended for the support of the oral arms; valves articulated by teeth and sockets.

As an example of this family I have figured the

FIG. 55.



SPIRIFER PRINCEPS.

Spirifer princeps, a common and characteristic Carboniferous fossil.

FAMILIES.	*Characters.*
3. *Rhynchonellidæ.* . .	*Shell* impunctate, oblong, or beaked; hinge line cur area; valves articulated, often sharply plaited; for neath the beak, usually c by a deltidium, sometim cealed; hinge teeth supp dental plates, supporting mellæ, rarely provided wi processes.
4. *Orthidæ.*	*Shell* transversely oblong, d rarely furnished with f hinge line wide and straig inconspicuous; valves pl vex, or concavo-convex, e a hinge area notched in th
5. *Productidæ.*	*Shell* concavo-convex, with a hinge line; valves rarely lated by teeth; closely a furnished with tubular ventral valve convex; do cave; internal surface dot conspicuous funnel-shape tures.

I have selected the *Producta punctata*, fro

FIG. 56.

PRODUCTA PUNCTATA.

Carboniferous limestone, to illustrate this rem able family.

FAMILIES.	Characters.
6. *Craniadæ.*	*Shell* orbicular, calcareous, hingeless; attached to rock by the umbo or whole breadth of the ventral valve; dorsal valve limpet shaped.
7. *Discinidæ.*	*Shell* attached by a pedicle passing through a foramen in the ventral valve; valves not articulated; minutely punctate.
8. *Lingulidæ.*	*Shell* oblong or orbicular, sub-equivalve, attached by a pedicle passing out between the valves; texture horny, minutely tubular.

If we compare, in Diagram IV., p. 312, the curve representing the life history of the Açephals with that of the Brachiopods, we shall find the following characteristics:—

It reaches a maximum gradually attained, at the end of the Lower Palæozoic period, in the Upper Silurian epoch; it then falls off somewhat, rises again, and reaches a second very remarkable maximum of nearly forty per cent. at the beginning of the Neozoic period. After that it falls off slightly again, reaches a minimum, and is now in the act of rising again perhaps to a third maximum, greater than its maxima in either in the Lower Palæozoic or the Neozoic periods. It is following, therefore, you will observe, in its own way, the law that we found to prevail among the Gasteropods, which reached a succession of maxima gradually increasing, and on passing through the Tertiary period were rising rapidly to a maximum evidently greater than any previously attained. So with the Acephals; they have a less number of maxima, but their progress is in the same direction. We have therefore reason to believe that the Gasteropods and the Acephals, from the time of their first introduction on the globe, have gone on

gradually increasing in the degree of their zoological importance.

VI. **Polyzoa.**—These Mollusks, commonly called Lace Corals, and formerly named Bryozoa, are more complex in their anatomy than the Corals, which they resemble in the circumstance that a number of individuals live together, and share a common life; the nourishment imbibed by each contributing to sustain the whole. The best known representative of the Polyzoa in recent times is the Flustra, or Sea Mat, so frequently washed up on our shores, and so often erroneously taken for a kind of seaweed. In addition to the Lace Corals, which are undoubtedly Polyzoan, there are two other remarkable groups of fossils referred by many geologists to this Order:—

Oldhamia.—These fossils are found in the Cambrian rocks of Bray Head, in the county of Wicklow, and are interesting from the fact that they were long supposed to represent the earliest traces of organic life on the surface of the globe. The remains hitherto discovered are referred to two species—*Oldhamia antiqua*, and *Oldhamia radiata*, which are well represented in the accompanying woodcuts, Figs. 57, 58, 59, 60, 61, and 62, which I have been permitted to make use of by the Royal Irish Academy.

Graptolites.—These well-known fossils are characteristic of the Silurian rocks, and are referred, probably correctly, by some naturalists to the Polyzoan Mollusks. They are formed of a slight, solid axis, fibrous, cylindrical, and furnished with longitudinal

* The best account published of Oldhamia is that by Dr. Kinahan, in the "Transactions of the Royal Irish Academy," vol. xxiii., pp. 550–557.

[To face page 324.

Fig. 57.

Fig. 58.

OLDHAMIA ANTIQUA.

Fig. 59.

OLDHAMIA RADIATA.

[To face page 324.

FIG. 60.

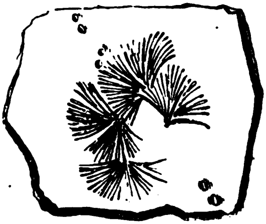
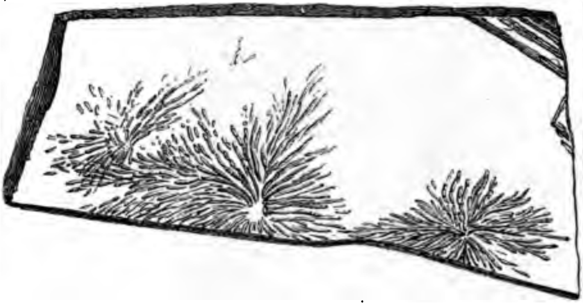


FIG. 61.

OLDHAMIA ANTIQUA.

FIG. 62.



OLDHAMIA RADIATA.

; provided with rows of Polyzoan cells, some-
ɩ at one side only, and sometimes at both sides.
single Graptolites are found in all the Silurian
ɩ, while the double Graptolites are confined ex-
vely to the Lower Silurian rocks. They are
ed, according to external appearances, into the
ving Genera:—Graptolithus, Rastrites, Diprion,
ograpsus, Didymograpsus, and Gladiolites.

LECTURE XIV.

CLASSIFICATION OF MAMMALS—NON-PLACENTAL MAMMAL FOSSIL MARSUPIALS—PLACENTAL MAMMALS—FOSSIL C NIVORES—FOSSIL UNGULATES—FOSSIL EDENTATES.

We have now to consider the history of the Fo Mammals. The Mammals are the most highly ganized of the whole of the vertebrate class. T vertebrate class is divided into Mammals, Bir Reptiles, and Fishes. I have shown you that birds and reptiles appeared, and reached proba their maximum of developement, at the commen ment of the Neozoic period. The fishes appear at an earlier period of the earth's history, at commencement of the newer Palæozoic peri The Mammals make their appearance after commencement of the Neozoic period; but were f in numbers until the close of the Neozoic period, the time immediately preceding the introducti of Man himself upon the globe. Their progress shown in the Diagrams I., II., III., p. 104; these No. II. is the curve of zoological importan which compares the number of species of Mamm present on the globe at a given time with t total number of species of every kind of anim present at the same time. You observe that continues at a very low point for a long time, a suddenly reaches a very great height at the end the Tertiary period.

In No. I., which indicates the rate of creation, or the number of species per mile of strata, you observe that the curve of the Mammals also continues low, and rapidly rises as you approach the Tertiary period.

All naturalists are agreed to divide the Mammals into two great groups, —the placental and the non-placental Mammals; and many consider that the latter should be regarded as composed of two groups of primary, and not subordinate importance:—

CLASS MAMMALS.

Subclass I., . .	ORNITHODELPHS [or MONOTREMES],	Non-Placental.
Subclass II., . .	DIDELPHS [or MARSUPIALS].	Non-Placental.
Subclass III., . .	MONODELPHS,	Placental.

I. Ornithodelphs.—In this Subclass the reproductive organs of the female, as the name implies, resemble those of birds. The oviducts are enlarged below into uterine pouches, which terminate severally in a cloacal chamber, common to the genital, urinary, and fecal evacuations. They are destitute of teeth, but possess horny plates instead. The coracoid articulates with the sternum, as in birds. They possess no true marsupial pouch, although bones regarded by some as marsupial are connected with the pelvis. This Subclass is unknown in the fossil condition, and is represented in modern times by two genera only; the Echidna and the Ornithorhynchus.

II. Didelphs.—These are so called from the fact that the oviducts open into vaginæ, more or less completely divided into two passages. They possess true teeth, and have the coracoid bone anchylosed with the scapula, and not articulated with the sternum. They all possess marsupial bones, which are ossifications of the internal tendon of the external oblique abdominal muscle; and are provided with a pouch, or *marsupium*, in which the young are suckled after birth. This marsupium is supported by the marsupial bones, which articulate with the pelvis, and are furnished with levator and depressor muscles.

In most of the Mammals that we are acquainted with the young is retained in the uterus of the mother until, at birth, it is capable of exerting for itself an act of suction. It is then suckled by the mother, and may be said to enter upon life capable of fulfilling all the functions necessary for its nutrition. The young of the Didelphic or Marsupial Mammals are not so perfect at the time of their birth. They are therefore placed by the mother after birth in the marsupium, which is external to the body, and in which the teats are situated, to which the young adhere by a process that cannot be considered to be an act of voluntary suction; it is rather an organic union established between the mouth of the young animal and the teat of the mother, and is not an act of independent voluntary exertion on the part of the new-born animal, such as we find in the more perfect animals.

The name of Monodelphic or Placental Mammals was given to the perfect Mammals in order to mark this distinction, the Monodelphic Mammals being those in which the young is at first lodged in a single uterus, and born perfect into the world; the Di-

delphic being those in which the young is placed at first in a uterus essentially double, and afterwards in an external pouch, or Marsupium,—so well known in the Kangaroo, the Opossum, and other such animals.

This distinction between the placental and the non-placental Mammals, you observe, therefore, indicates that the placental Mammals are superior to the others, because the non-placental Mammals form by the very mode of the early nourishment of the young a sort of intermediate stage between the oviparous and the viviparous animals. In the oviparous animals the young are born from an egg, which is hatched entirely external to the body of the mother; and therefore the animal which is half developed in the body of the mother, and then perfected afterwards outside in an external pouch, may be regarded evidently as inferior to the perfectly viviparous, and superior to the oviparous class of animals.

The Monotremes, as is well-known, are inferior to any of the Marsupials in their organization. There are anatomical reasons for considering them to be the lower group. The simplest and most obvious of these anatomical reasons is the one which gives them their name, that in the Monotremata the same cloacal chamber serves for the termination of the intestine and for the genito-urinary organs. In this respect, therefore, the Monotremata alone of the Mammals resemble the birds; and this very low type of organization marks them out at once to be the lowest and most inferior of the whole group.

It is a well-established fact that the Marsupials appeared in the Oolitic period, long before the Placentals; but whatever speculative inferences as to

progression of animal life, and the succession of forms by natural descent, we might be inclined to found on the fact that the first Mammals that were created and appeared on the globe were non-placental, receive a rude shock from the fact that the most imperfect of them all, the Monotremata, are rigorously and strictly confined to the living creation. Not a single specimen of the Monotremata has ever been found among the fossils. In the continent of Australia, in which the Marsupials are so abundant, not a single Monotrematous animal—which one would expect should have preceded the Marsupials, if there were a natural law of progress—is to be found; and it remained for our own times, for a period within the history of the human race itself, that this most imperfect and unfinished form of the Mammals should be created and placed upon the globe. This is a case precisely analogous to that which I have already called your attention to, viz., that of the flat fishes, where, as if to disprove our theories and to spoil our systems, it was reserved for our own times to have created and placed upon the globe the most imperfect and degraded of all the types of the class of the animal kingdom to which they belong.

The oldest Marsupial as yet found fossil is the *Microlestes antiquus*, of which some molar teeth were found by Professor Plieninger, in 1847, near Stuttgard, in a breccia which forms in that locality the uppermost bed of the Triassic deposits. This animal resembles, as to the form of its teeth, another better known Marsupial from the Purbeck beds in England, called *Plagiaulax Becklesii*, which is an herbivorous Marsupial of rodent character, resembling the Kangaroo-rat.

A Marsupial lower jaw has been found in the

Triassic beds in North Carolina: the animal to which it belonged is called *Dromatherium sylvestre;* its nearest analogue in modern times is the *Myrmecobius;* for each ramus of the lower jaw contained ten small molars in a continuous series, one canine, and three incisors, divided by short intervals.

The earliest description of fossil Marsupial bones was given by Dr. Buckland, in 1823, from an examination of two lower jaw bones found in the Stonesfield slate of the Oolitic period, in England. One of these belonged to a Marsupial allied to the Opossum, with four molars and three premolars, which has had the name *Phascolotherium Bucklandi* given to it.

The other jaw has been proved to be also Marsupial, and is remarkable from the number and distribution of its teeth. It contains six molar, six premolar, one canine, and three incisors at each side. This fossil is called *Amphitherium Prevosti*, and is believed to be allied to the insectivorous Marsupials. Another mammalian jaw has been found in the Stonesfield slate, belonging to an animal which has been called *Stereognathus;* but nothing certain is known respecting it, not even whether it was Placental or Marsupial.

In 1854, and subsequently, there were found by Mr. Brodie and Mr. Beckles, in the middle Purbeck beds, in Durdlestone Bay, numerous jaws containing teeth, which on examination proved to belong probably to various small Marsupials. These are referred to twelve or more species of genera called Spalacotherium, Plagiaulax, Triconodon, Galestes, of which little more is known than that they were probably Marsupial, and either insectivorous or rodent in character.

Marsupial remains are found in abundance in the Tertiary beds of Europe, America, and Australia, some of them being referrible to living genera, such as the Opossum; and in the Post-tertiary deposits the Marsupial fossils attain gigantic dimensions, comparable with those of their Placental contemporaries.

The Marsupial remains found in the older rocks belong to very small animals. The jaws, which are the principal parts preserved, are exceedingly minute; and it is not until we approach the later portion of the Tertiary period, where the curve of the Mammals approaches the age of man, and reaches its maximum, that the Marsupials, as well as the other more perfect Placental Mammals, acquired the extraordinary developement which entitles the later portion of the Tertiary period to be called the Mastozoic Age.

It was at the close of the Tertiary period that the gigantic Marsupials which have been recently found in Eastern Australia occurred. The *Diprotodon Australis*, whose remains have been found in the caves of the Wellington Valley, near the Condamine River, west of Moreton Bay, was a Marsupial with incisor tusks, and five molars in each jaw, the crown of which is formed of two transverse ridges, arranged as in the Tapirs and Kangaroos, but more compressed and elevated. The lower angle of the jaw is prolonged into an horizontal process, turned inwards, for the attachment of powerful pterygoid muscles, as in all the Marsupials. This remarkable fossil was as large as the Hippopotamus, and represented the Pachyderms in the Marsupial series; so furnishing an additional proof of the parallelism that subsists between the Orders of the Placental and Non-placental Mammals.

While these pages were going through the press, a discovery was made in France that transfers the largest of Fossil Mammals from the Placental to the Marsupial division. Science owes this important discovery to a distinguished member of the religious society whose enthusiastic zeal in advancing knowledge and religion is felt throughout the world. Father Sanna Solaro, of the Society of Jesus, discovered, in the department of the Haute Garonne, the pelvis of the *Dinotherium*, hitherto known to us only from the examination of other bones; and has proved that this supposed aquatic herbivorous Pachyderm was a gigantic Marsupial; and that the dependent tusks of her lower jaw, instead of serving the purpose of anchoring her to the banks of rivers, answered the more homely, but equally important office, of lifting her young into the maternal abdominal pouch.

The bones previously found, and speculated on, were the jaws and shoulder blade, from the size of which it was supposed by Cuvier and Kaup to have attained the extraordinary length of eighteen feet, and to have used its anterior limbs principally in the act of digging for roots. The remains on which these speculations, and the subsequent romances of Buckland were founded, were discovered at Eppleshein, in Hesse Darmstadt, and in several parts of France, Bavaria, and Austria.

Father Solaro's specimen is a pelvis of immense size, six feet in breadth from crest to crest of the iliac bones, and $4\frac{1}{4}$ feet in height from the inferior symphysis of the pubis to the extremity of the superior spine of the ilium. These measurements exceed those of the largest fossil Elephants and Mastodons. In this pelvis, between the acetabulum and inferior

spine of the ilium, an articulating groove, of tr
gular shape, was discovered; and in this groove
one of the two sides, the triangular bone that fi
the articulating surface on the ilium was fou
and a portion of a similar bone detached, and
dently belonging to the other side. These are m
supial bones, and they articulate with the ilium

Anatomists consider the marsupial bone to be
analogue of Poupart's ligament in Placentals, wh
is stretched from the spine of the pubis to the an
rior superior spine of the ilium; and in recent
mals the upper part of the marsupial bone is fi
and the lower is articulated with the crest of
pubis. In the Dinotherium this bone is articula
with the ilium, and not with the pubis, in order
allow of room in the marsupium for the greater s
of the young animals. The Dinotherium, therefo
was not an herbivorous Cetacean, but probably
elephantine Marsupial; and the remarkable histo
of the successive discovery of its bones, and t
change of views consequent thereupon, should tea
geologists modesty in the expression of their o
nions.

III. Monodelphs, or Placental Mammals.—The
are the highest and best known of the Mamma
and retain the young *in utero*, until it is able
suck milk from the teats of its mother by volunta
action.

Many classifications have been proposed of th
important Subclass; of these I shall adopt that of M
Dana as the most convenient for my present pu
pose.

Placental Mammals (excluding Man), arranged
two parallel series:—

Megasthenic.	Microsthenic.
I. Quadrumans.	I. Chiropters.
II. Carnivores.	II. Insectivores.
III. Ungulates.	III. Rodents.
IV. Mutilates.	IV. Edentates.

	Characters.
I. Quadrumans, . . .	The limbs, or at least the posterior furnished with hands,—that is, having a thumb opposable to the fingers for grasping; two incisors in each jaw; perfect clavicles; pectoral mammæ.

The Quadrumans include the following Families:—

1. *Strepsirhine*, having curved or twisted terminal nostrils, and the second digit of the hind limb a claw. Madagascar. Example—Lemur.
2. *Platyrhine*, having the nostrils subterminal, and wide apart; the thumb of forelimb not opposable, or wanting, and the tail prehensile. South America. Example—Marmoset.
3. *Catarhine*, with nostrils oblique, and approximated below, opening above and behind the muzzle; thumb of forelimb opposable. Africa and Asia. Examples—Baboon, Orang.

The Quadrumans are not known in the fossil condition in strata older than the Tertiary, and in these strata they are by no means numerous, and are referrible generally to existing genera. It is worthy of notice that their geographical distribution is similar to that now prevailing, so that Catarhine monkeys only are found fossil in Europe and Asia, and Platyrhine monkeys only in South America.

	Characters.
II. Chiropters, ...	Having wing-like expansions of the forelimbs; pectoral mammæ; hibernating. Example—Bat.

Mammals of this Order are found fossil in the Tertiary beds of Europe and Brazil; but they seem to have been as rare in former times as they are at present. The most celebrated fossil bat is the *Vespertilio Parisiensis*, found in the gypsum beds of Montmartre, and described by Cuvier:—

	Characters.
III. CARNIVORES, . . .	Feet with claws, the lower surface having the special sense of touch; three incisors (except the Seals, which have three in the upper jaw, and two in the lower); canines longer than the other teeth; molars trenchant or tuberculate, according as the food is more or less completely flesh; clavicle rudimentary, or wanting.

The Carnivores are divided into three Sub-orders:—

1. *Digitigrade*, walking on the toes without touching the heel to the ground. Examples—Cat, Dog, Lion.
2. *Plantigrade*, the palm of the hind feet touching the ground in walking. Examples—Bear, Badger.
3. *Pinnigrade*, swimming by means of fin-like paddles. Examples—Seal, Walrus.

The Digitigrade Carnivores are represented in the middle and newer Tertiary beds by several species of felines, analogous to the lion, called Machairodus; these animals have been found in Auvergne, in the Val d'Arno, and in Devonshire. In Post-tertiary deposits these animals are replaced by the *Felis spelæa*, a lion larger than any existing species: the remains of this animal have been found in bone caverns in different parts of Europe; and in Banwell, Somersetshire, in England.

Among the fossil Digitigrade Carnivores we must also reckon the celebrated *Hyæna spelæa*, so often found in England, where it seems to have represented the cave bear of Germany.

The Plantigrade Carnivores are well represented in the fossil condition by numerous species of bears found in Post-tertiary caverns all over Europe. The most famous and largest of those is the *Ursus spelæus*, which is so numerous in some localities, that upwards of 800 individuals have been identified in a single cave, as that of Gailenreuth, in Germany.

The geographical distribution of fossil bears in Post-tertiary times throws considerable light upon changes supposed to have occurred in the climate of recent periods. Thus, at Lough Gur, in the county of Limerick, Dr. Alexander Carte has recently found the thigh bone of the polar bear, which was identified principally by means of the posterior intertrochanteric line, developed for the attachment of the *quadratus femoris* muscle. This bone was associated in the mud of Lough Gur with a human skull of the Lapland type, and with a small padlock of the Birmingham pattern.

The Pinnigrade Carnivores are represented by a few Seals from the middle Tertiaries, and a Walrus found in Russia.

	Characters.
IV. INSECTIVORES, . .	Molars studded with conical points, and associated with incisors and canines. Examples—Mole and Hedgehog.

These Mammals are represented by a few fossil species found in the middle Tertiary and later periods. They are particularly interesting to the student, from the general resemblance that their

lower jaw bears to that of several of the smaller Marsupials. This resemblance is so great, that many anatomists hesitate to refer some of the jaws found in the Purbeck beds to the Marsupial Sub-class until evidence is found of the existence of the horizontal process in the lower jaw characteristic of the Marsupials.

	Characters.
V. UNGULATES. . . .	Feet hoofed, unfit for grasping, and of low tactile sense; the limbs restricted in use to support and locomotion; molars with broad summits for grinding; no clavicles.

This Order of Mammals is divided into two Sub-orders, according as the toes are odd or even in number:—

1. *Artiodactylic Ungulates.* Dorsolumbar vertebræ nineteen in number; horns, if any, in pairs; contain the two groups of,

(*a*) *Ruminants*, . . .	That chew the cud. Examples—Deer, Sheep;
(*b*) *Omnivores*, . . .	As the Pig, Hippopotamus.

2. *Perissodactylic Ungulates.* Dorsolumbar vertebræ more than nineteen in number; horns, when any, never in pairs; contains the three following groups:—

(*a*) *Solidungulates*, . .	One-toed. Example—Horse.
(*b*) *Multungulates*, . .	Three or five-toed. Example—Tapir, hind foot three-toed, and fore foot four-toed.
(*c*) *Proboscidians*, .	Rhinoceros, three-toed. Elephant, five-toed, with proboscis and tusks from one or both jaws.

The Order of Ungulates is well represented in

[To f

Fig. 63.

FOSSIL RED DEER.
(Co. Fermanagh.)

[To face p

Fig. 64.

FOSSIL REINDEER.
(Co. Dublin.)

the fossil condition, and both its divisions contain species larger than any now living.

The most remarkable of the fossil Ruminants are found among the Deer tribe, the largest of which is the *Sivatherium giganteum*, found in the Tertiary beds of the sub-Himalayan hills. It was a deer with four horns; and from comparative measurements of its bones and those of the great Irish deer, *Cervus megaceros*, I consider it to have been of eight times the bulk of the latter. If this estimate be correct, it must have exceeded the elephant in its dimensions.

The Irish Deer, *Cervus megaceros*, possessed branching palmate horns, often weighing 80lbs., and is found in the bogs and shallow marls of Ireland, under circumstances that lead us to believe it to have been the contemporary of the earliest human inhabitants of Ireland, who probably killed and ate it.

The Marsh Deer, *Cervus elaphus fossilis*, found with the gigantic Irish Deer, and with heads of pigs killed by human agency, is shown in Fig. 63, which represents a skeleton preserved in the Museum of Trinity College, and found in the county of Fermanagh. It differs from the recent Red Deer in its greater size, and in having thirteen instead of twelve ribs.

The Reindeer, *Cervus tarandus*, formerly existed in Ireland, as the contemporary of the Polar bear, and men of Lapland type. A head and horns found in the county of Dublin, and preserved in the Museum of the Royal Dublin Society, is shown in Fig. 64.

The fossil Omnivores include the Pigs with two toes, and the Hippopotams with four. Fossil pigs are

found in abundance in the Tertiary beds of Amer and fossil Hippopotams are among the most markable Tertiary and Post-tertiary remains Europe. The great Riverhorse of Africa, whic tains a length of eleven feet, is found at presen where north of Abyssinia; but in the Mastozoic riod it ranged freely over France and England, w its remains are now called *Hippopotamus m* and which seems specifically identical with the ing African species. This Hippopotamus has incisors in each jaw; but a fossil species has found in India, with six incisors, in Tertiary d sits. The fossil species exceeded the living in but were probably the ancestors of our degen contemporaries.

The Anoplotherium of the older Tertiary be Montmartre must be reckoned among the two- Omnivores, for it was not a Ruminant. Cu considers its habits to have been aquatic, like t of the Hippopotamus.

The Solidungulates are represented by fossil ho found both in America and the Old World, whic the former country must have become extinct; is well established that the horses now found li in America were introduced by the Spaniards.

The Multungulates are well represented by *Rhinoceros tichorinus*, a hairy species found all the temperate and subarctic Post-tertiary dep of Europe and Asia; and by the Palæotherium its allies, found by Cuvier in the older Tertiary of Montmartre.

The Proboscidians of the Mastozoic epoch, the Ruminants and Marsupials, were gigantic in and are best known by the Mammoth, or *Ele primigenius*, of Europe and Asia, and the *Mast giganteum* of North America.

The Mammoth formerly inhabited Siberia, and was protected from the cold climate of that country by a double coating of long hair and short fur; it lived on branches of birch trees, and is often preserved in icy gravel, with the flesh adhering to the bones. The eyes, hair, and ligaments of the joints are well shown in some specimens preserved in the Imperial Museum of St. Petersburgh. The natives of Siberia and Northern China believe the Mammoth to be a gigantic mole, which burrows under ground, and perishes whenever, by mischance, its burrow reaches the light of the sun.

The Mastodon is distinguished readily from the Elephant by means of its teeth, and in North America attained a size comparable with that of the Mammoth of Siberia. The largest specimens have been found in the State of Ohio:—

	Characters.
VI. RODENTS, ...	Molars with flat grinding summits; two long incurved incisors in each jaw, separated by a wide space from the molars. Examples—Rat, Beaver, Hare.

All the Families of the Rodents are found represented in the Tertiary and Post-tertiary deposits, by species closely allied to living ones; but they offer no striking peculiarity worthy of being noticed in so general a review as this necessarily must be.

	Characters.
VII. MUTILATES, ...	Limbs short, and paddle-shaped for swimming.

The most remarkable of the fossil Whales is the *Zeuglodon cetoides*, from the Tertiary beds of Alabama; some of its larger vertebræ are one foot

and a half long, by one foot wide, and were formerly so abundant in parts of Alabama, that they were used for making walls, or burned to rid the fields of them. This whale attained a length of seventy feet, which is, however, exceeded by that of several living whales. Its dentition is peculiar, and it derives its name from the circumstance that the fangs of the tooth are structurally prolonged far up in the tooth itself, so that the latter, when worn down by mastication, resembles two flat islands of bone united by a narrow isthmus.

	Characters.
VIII. EDENTATES, . . .	Incisors and canines, with few exceptions, wanting; sacrum formed of two united vertebræ, as in reptiles; teeth without enamel, growing as they become worn down; legs with claws, and motions of body slow.

This remarkable and undeveloped Order is represented in existing nature by the Armadilloes, Sloths, and Anteaters of South America, none of which are larger than a small-sized dog. They are natives of South America, from which country are also procured the fossil remains of the gigantic Edentates of the Mastozoic period, which have rendered this Order so interesting to geologists and naturalists.

The most remarkable of the fossil Edentates is the Megatherium, a fossil Sloth exceeding the Rhinoceros in bulk. It possesses five molars in the upper jaw, and four molars in the lower jaw; the coracoid and acromion processes of the scapula are united, and it possesses a powerful S-shaped clavicle; which circumstance, combined with a very unusual power of pronation and supination of the

[To fac

Fig. 65.

MYLODON ROBUSTUS.

forearm, indicates habits totally unlike those of any living animals of its size. The pelvis measures 4½ feet from rim to rim, and has the acetabulum directed vertically downwards, so giving the femur the office of bearing directly the enormous weight of the body. The enormous transverse processes of the caudal vertebræ—some of which measure 18 inches across—correspond with this anatomical peculiarity of the pelvis, and indicate, when taken in connexion with the structure of the arms, that the animal probably supported the weight of the body on a tripod formed of the legs and tail, thus leaving its arms free to tear down the branches of the trees which formed its usual food.

The *Megatherium Cuvieri* was twelve feet long, and five feet high, and is calculated to have exceeded by one hundred fold the largest of existing Edentates.

In Fig. 65, I have shown, after D'Orbigny, the *Mylodon robustus*, from Buenos Ayres, an animal closely related to the Megatherium, but inferior to it in dimensions, as it only attained a length of nine feet.

FIG. 66.

GLYPTODON CLAVIPES.

In Fig. 66, is shown the *Glyptodon clavipes*, the most celebrated of the Edentates of the Armadillo type, found in the Mastozoic deposits of South America. Its total length is nine feet, and it measures five feet along the curved ridge of the back of its shell, which resembles that of a turtle.

The Mastozoic epoch, as I have shown, was characterized by the existence of enormous Mammals, belonging principally to the following Orders:—

1. MARSUPIALS. . .	Diprotodon, Dinotherium.
2. UNGULATES. .	Artiodactylic–Sivatherium, Megaceros. Perissodactylic–Mammoth, Mastodon.
3. EDENTATES. . . .	Megatherium, Glyptodon.

This remarkable epoch immediately preceded the Anthropozoic epoch, in which we live; and the concurrent labours of archæologists and of geologists tend to prove that the termination of the reign of Mammals on the globe was mainly due to the creation of the race of Man, who is endowed with faculties which enable him to destroy with ease all rival races, however superior to him in the brute qualities of size and strength.

It is the fashion of some modern naturalists to regard Man as the natural descendant of the Mammals that preceded him; but the evidence of geology is conclusive against this view; for the connecting links between the Mastozoic and Anthropozoic epochs are nowhere to be found; and, so far as this science teaches, the Mammals were in no other sense the originators of Man, than the Hebrews or Assyrians were the originators of the Greeks or Romans; they preceded them, and were replaced by them, but were in no intelligible sense their ancestors.

Man is the direct product of the creative power of God, and governs the other creatures by His express decree.

LECTURE XV.

GEOLOGICAL EPOCHS—RADIATES AND MOLLUSKS—CRUSTACEANS AND VERTEBRATES—EMBRYOLOGICAL THEORY—THEORY OF LAMARCK—THEORY OF DARWIN—THEORY OF CAUSATION—CONCLUSION.

In the course of the preceding Lectures we have traced in succession the progress of the different forms of life through the successive geological epochs. You will recollect that we assumed as our measure of time the thickness of the strata, the whole of which amount to twenty British miles, which are divisible into four well marked and nearly equal periods. The first five miles of thickness correspond with the Eozoic rocks, regarding which I believe, in common with most geologists, that but few traces of life have been found in them, principally because but little life existed during their deposition; the next portion, which occupies a space of time measured by ten miles of rocks, is universally called the Palæozoic period; and the last portion, which for convenience is often subdivided into many minor epochs, goes by the name of the Neozoic period, and occupies five miles in thickness, or one quarter of the total length of the history of the stratified rocks upon the globe We followed throughout this long series of fifteen miles of rocks, constituting the upper three-fourths

of the stratified crust of the earth, the great classes into which the Animal Kingdom is subdivided; and what I have now to lay before you is a sketch, which must be necessarily brief and imperfect, of several of the most celebrated and interesting theories which have been formed to connect together the progress of these forms of life, with their history in time. Before doing so, I shall briefly recapitulate the results at which we arrived with regard to the life history of these great divisions of the Animal Kingdom.

In following the history of the Protozoa, from the earliest periods to the present time, we found that the different groups of Protozoa are fairly and well represented at all periods of the earth's history, with a tendency during the earlier parts of the Palæozoic period to the developement of types of the Protozoa, larger and on a greater scale than any with which we are now acquainted.

With respect to the Radiata proper—not the Radiata of Cuvier, because from the Radiates of Cuvier we remove the Echinoderms, and place them in a higher group; but the Radiata proper, which are principally represented in the fossil condition by Corals—we find a history of life quite similar to that which we find in the Protozoa, namely, that at all periods of the earth's history the coralline forms had pretty nearly the same relative degree of importance, as compared with the rest of the creation, that they possess at the present time; but we do not find in those coralline forms a tendency to the developement of larger or more gigantic types at one period of the earth's history than at another.

Passing next upwards in order of zoological dig-

nity to the Molluscan group, and confining our attention to the first four of its subdivisions, which are principally represented in the fossil strata, we arrive at results differing completely from those which we found in the case of the Protozoa and the Radiata, and which possess a very high degree of interest. Of these groups you will remember that the Cephalopods were the highest in organization, and the Brachiopods the lowest. These two groups, the highest and the lowest of the fossil Mollusks, follow a corresponding law of developement in time, and are to be regarded at the present time as groups which are in the act of becoming extinct. The variety of forms which existed in the fossil periods of these two great groups, the Cephalopods and the Brachiopods, was much greater than that which now exists, and naturalists find the greatest possible difficulty in drawing inferences, of value to the geologist, with regard to these extinct forms of Mollusks, owing to the imperfect knowledge that we possess of them in their recent forms. The second and third groups of the Mollusks, viz. the Gasteropods and the Acephals, follow an order of developement in time quite different from that which the first and fourth followed. They commence their life history upon the globe about the same time as the first and fourth, but they gradually increase in zoological importance until they reach their maximum in recent times. These facts with regard to the Mollusca are clearly shown in Diagram IV., p. 312, where the horizontal lines represent time, and the vertical lines zoological importance. The curve of the Cephalopods is represented by a line which reaches a maximum in the Palæozoic period, a second maximum in the

Neozoic, and then descends to a small minim The Brachiopods reached one great maximum the Palæozoic period, and afterwards fell off, never again acquired their former importance. the other two groups, viz. the Gasteropods and Acephals, rise, as the Diagram shows by a co nually increasing succession of maxima, till at present time they have an amount of zoological portance greater than ever they possessed before. these remarkable facts regarding the developen of the Mollusks we must add the fact that the chiopods, which abounded in the earlier peri are regarded by naturalists as having striking af ties to the embryonic or early condition of the A phalous bivalves.

With regard to the Articulate group, the Cru ceans are, geologically, the most important. showed you that the Crustaceans acquired a deg of zoological importance in the lower Palæozoic riod, that entitles that period justly to be called Age of the Crustaceans, or Malacozoic epoch.

For the Vertebrate animals—Fishes, Reptiles, Bi and Mammals—we find a corresponding histo The Fishes reached their maximum of importance the Upper Palæozoic period, and they ever afterwa declined; the Reptiles reached their maximum of i portance at the commencement of the Neozoic riod, and the Mammals reached their maximum zoological importance at the close of the Neozoic riod, and immediately previous to the creation Man. With regard to these important groups, a markable law, of which we saw the first instance in t case of the Protozoa, is clearly developed—name that the fossil forms included creatures of these kin greater and larger than any that are now known.

the Age of the Crustaceans, individual Crustaceans were developed of a size and on a scale that do not now exist; during the predominance of the Reptiles the same fact occurred, and a number of Reptiles larger and more important than any which now live formerly existed, and, as I showed you in the last Lecture, the same fact appears with regard to the Mammals. A similar assertion may also be made respecting the fossil Birds, which indicate the same law of gigantic size that characterizes the other Vertebrate animals.

With regard to the important question, whether in the Crustaceans and Vertebrate animals the existing forms of life were more or less perfect than the present forms, the conclusions to be drawn are different in the different groups. In the Crustaceans, naturalists consider that they have evidences, such as are to be found in some of the Molluscan groups, of a more embryonic condition. In the Fishes, the evidence is contradictory; and while some naturalists of eminence maintain that the early fossil forms were embryonic, and infer therefore that they were inferior in organization to the recent Fishes, we must remember that remarkable exceptions occur, and that amongst the most recent Fishes, confessedly the most imperfect and least developed forms are to be found, as in the case of the flat Fishes, or Pleuronectoids. With regard to Birds we have such imperfect information, that we can draw no inference with regard to the relative zoological position of the former and the latter forms. The argument from size would be a fallacious argument, because the largest creatures are not always the most highly organized. With respect to the Mammals, nearly the lowest form of Mammalian life, the Marsupial

type, was first created, and afterwards the Placental Mammals; but as an exception to this rule, and as if to call our attention to the fact that we are not to generalize too hastily from such observations, we find among living creatures the Monotremes, most imperfect forms of Non-placental Mammals, which are unknown in the fossil periods. These creatures occupy, therefore, a position with regard to Mammals similar to that which is occupied with regard to Fishes by the flat Fishes of modern times.

With regard to the evidence afforded by fossil Plants, we find that the fossil Plants of the great period when the vegetation of the earth flourished on a scale which has not occurred before or since, belonged principally to the imperfect orders of vegetation, such as the club mosses, the ferns, and the horse-tails; and that those imperfect forms of vegetable life at that time acquired a size which enabled them to rival that of our largest forest trees.

Such I believe to be an honest and faithful sketch of the actual facts; and on such facts all theories of the Life History of the Globe must necessarily be based.

The first theory to account for the appearance in succession of these creatures on the globe that I shall notice is the celebrated theory which was put forward by the author of the "Vestiges of the Natural History of Creation." It may be characterized as the embryological theory of life upon the globe. It starts from the supposition that the most highly organized animals pass during the fœtal condition successively through phases characteristic of the lower forms of life; and zealous naturalists of this school, endowed with the faith requisite for such specula-

tions, have never failed to find, even in the human fœtus, that it passes successively through the several phases of the Fish, the Reptile, the Bird, and Man. The life of the globe itself is fantastically compared, as is often done by modern speculators, to the life of an individual; and we are called upon by this theory to believe that our great mother earth, in producing her creatures in succession, followed the course adopted with regard to the production of the individual; and that the life of the globe, like the life of each one of us, has passed in succession through all those phases of imperfect developement which were gradually evolved from one another, from the less perfect to the more perfect form. It is not to be wondered at that so attractive and symmetrical a theory should find numerous supporters. It has therefore always been popular; but it has not received the ready assent from thinkers that it has from popular lecturers and readers. In fact, its very symmetry renders it dangerous and suspicious. We do not find that nature acts with this degree of regularity and symmetry in any of her works; and as a rigorous consequence from this theory it would follow that of necessity the dignity and importance of each creature on the globe would be an exact measure of the time at which it lived. You will observe from the facts that I have again and again brought under your notice, that numerous exceptions to the law of progress are to be found in geology. Now, one single exception would be fatal to this theory; and as the exceptions are numerous—although I readily admit that there is abundant evidence of progress on the whole—I consider that we are entitled to set aside this theory as amongst these beautiful things that we may dream of in our

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the theory of degradation. Both Buffor
laboured under the great disadvantage
acquainted with the past history of the
that they studied; they were only ac
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Buffon devised the theory, the parallel
be found in Linnæus' speculations resp
that the Creator had originally plac
globe certain types of animals and
that by cross-breeding and intermixi
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of life which which are to be found in
classifications. Lamarck adopted t

ture on the globe was absolutely and completely formed by the physical and organic conditions by which it was surrounded.

Thus one group of animals might retrograde, another might ascend, but all would do so moulded by the circumstances by which they were surrounded. And in the statement of this remarkable and extraordinary view, Lamarck occasionally falls into the use of language which, to a person who is not a believer in the theory, borders closely upon the ridiculous. He attributes, sometimes incautiously, to the animals a desire to alter their condition; he attributes in particular this ambition to the monkeys who, by the exercise of this constant desire to improve and to tyrannize over their brother monkeys, gradually succeed in producing man! Other forms, no doubt—like the flat Fishes and the Monotremes among the Vertebrate animals—not endowed with this wish to better their condition, must have had the perverted and degenerate wish to degrade themselves. But, of course, Lamarck only falls occasionally and incidentally into these expressions, which attribute volition to the animal in changing its condition. The fair and true statement of this theory would be, that the creature becomes the necessary consequence of its surrounding conditions. Mr. Darwin draws logical consequences from Lamarck's theory. He had the advantage over Lamarck of being acquainted with the history of the life of each creature on the globe, as well as with their present condition; and he introduces a speculation or theory which was intended to account, not merely, as Lamarck attempted to do, for the existence of present creatures on the globe, but to trace them back through time, to follow their history, and to show how they became what they

physical and organic conditions chang
of animals. He attributes it to the con
food and females—to the contest for lif
tence—the constant struggle that is al
on between animals of every kind, bein
and fiercest between animals that are
to each other in their organization. T
will follow that any accidental deviatio
existing type of animals that will give th
vantage in this competition for food, a
means of reproduction, will become hered
be propagated; and so a group of creat
adapted to their surrounding circumstan
the result, because those possessed of t
will defeat their rivals not possessed o
battle of life. You will observe that thi
is quite unnecessary to the Lamarckian th
that the latter theory, which makes th
the product of the surrounding circumstan
remain if this principle were abandone
is an attempt to assign a cause for the

to me that this is an assumption fatal to the theory itself. Our experience, as far as it goes, of breeding varieties of animals, of producing them artificially, or observing them as they are produced by nature, seems to show that this power of adapting itself to surrounding circumstances is only a provision or safeguard given to the species by the Creator to prevent its total destruction by any, even the slightest alteration, in surrounding circumstances. If the circumstances in which man, or any species of creature upon the globe were placed, were perfectly immutable and unchangeable, we might then suppose in the structure of the creature itself a corresponding immutability and unchangeableness. But as the circumstances of climate, of food, of conditions of every kind that surround us, are liable to vary, we should expect, in conformity with our views of the wisdom of the Creator, that he would endow His creatures with a power of deviating somewhat from the original type according to which He made them, so as to accommodate themselves to surrounding circumstances. But I have no hesitation in saying that every such deviation from the original type produces a monstrosity, and is in itself an imperfection, and not an advantage. It is well known to dog breeders, to pigeon fanciers, to horse and cattle breeders of every kind, that the production of particular types of animals in a direction which we want is accompanied by an alarming and fatal tendency to various diseases, so that the wild animal is always a healthier and stronger animal than the artificial animal, which is bred in a particular direction by the art of man. And there are many other indications in the same direction which seem to me to point out clearly and unmistakeably that the amount of de-

viation from the original type is strictly limited—within different limits in different creatures—and that the deviation from the original type, as it proceeds in conformity with surrounding circumstances, must ultimately reach a limit when the destruction of the species and of the creatures itself must be the result.

I have now laid before you, Gentlemen, as fairly as I possibly can, the embryological theory of Combe, and the politico-economical theory of Lamarck and Darwin; and I think you will see the strongest reason to be dissatisfied with both of them. The embryological theory is obviously untrue, and at variance with many exceptions that we are acquainted with in the history of the globe; and as, of necessity, the theory will not admit of a single exception, this alone entitles us to reject it. Lamarck and Darwin's theory possesses the advantage over the embryological theory, that it does not require strict progression; the animals, according to surrounding circumstances, may some of them progress, and others may retrograde; and so an imaginative mind may find ready excuses for the occurrence of the flat Fishes and the Monotremes in modern times, and will be able to apologize for the occurrence of the Cephalopods in the earliest periods. But it appears to me that this theory, resting as it does altogether on an unproved hypothesis, and one which the life of man or the succession of lives of men will for ever be unable to prove, wants that positive basis which it is desirable that science should endeavour to seek. It is also open to a fatal and serious objection that I would urge against all these theories—an objection that I believe will be found to extend not only to

these theories, but to many metaphysical doctrines that are commonly taught amongst us.

I believe that a good deal of the ready reception which such loose theories of the history of life upon the globe have received in modern times has been owing to the shallow metaphysical philosophy of the Scotch school. We have been taught by our teachers to believe that succession implies causation. We have been taught, that if an event uniformly follows another event, we are to call the first event a cause, and the second event an effect. As far as we are in a position to speak on the question, it appears to me that the various forms of life which have existed upon the globe can only be said to have succeeded each other in a certain manner which we can describe; but to attempt to show why any form of creature that appeared in the Palæozoic times was necessarily succeeded by others that appeared later in those times, and these again by totally different forms of creatures in the Neozoic period, followed closely by the apparition of Man himself, seems to be about as rational as to say that Sunday is the cause of Monday, Monday the cause of Tuesday, and Tuesday the cause of Wednesday. Or, taking a better comparison—the seasons of the year—we know that winter precedes spring, spring precedes summer, and summer autumn; but no person would say that winter is the cause of spring, spring the cause of summer, and so on, although we do know that some one and common cause exists, which is the cause of the seasons and of their orderly succession. This common cause in the seasons we are acquainted with; and if we could reach it in the history of life upon the globe, it would explain to us how it is that

these creations succeed each other. We must remain, I believe, for ever ignorant of the principle which regulates the succession of life upon the globe, and pending the arrival of more perfect knowledge—which I think we have no right to hope for, or to expect—we must remain contented with the very old-fashioned, but very simple and very satisfactory, hypothesis of a Creator.

I am well aware, Gentlemen, that I should feel ashamed to be obliged, in the lecture halls of such an institution as this, to offer an apology for the existence of a Creator; yet such has been the lamentable tendency and progress of modern speculation, unfortunately not confined to geological science, in late periods, that such an apology really is not out of place. These various schemes to explain the history of life upon the globe appear to me to be ingenious modes of more or less politely bowing the Creator of the universe and o ourselves to the confines of His dominions, and o excluding Him virtually from our thoughts. Wha can be more simple, what can be more satisfac tory, than the theory of life upon the globe that there was a progress according to the Crea tor's will; that the various creatures, whose fos sil forms excite our admiration, and lead us t see the perfection of His works, were formed b Him in succession upon the globe according as H provided external circumstances suited to their ex istence; and that the order of succession might hav been different from what it is, if He had pleased It appears to me that to a religious mind nothin is simpler, nothing more intelligible or instructiv than the study of the history of life upon the glob referred continually and constantly to the Creator'

power always present. That there was a progression, and that perhaps some law, which we may at a future time be permitted to obtain a glimpse of, guided and directed that progress of life upon the globe, there appears to be little doubt. But in the present state of our knowledge I believe it to be safer, and at the same time more reverent, to attribute the order of life, and the succession in which it has appeared upon the globe, to a direct effort of the Creator's will, "in whom we ourselves live, and move, and have our being," and to whom we look for the fulfilment of our hopes of immortality.

It would be wrong, Gentlemen, if I concluded this course of Lectures, as I said before, without urging upon you the importance of retaining in your minds the sense of the constant and presiding presence of the Creator, moulding the history of the globe. But I would be equally wrong if I closed these Lectures without expressing my conviction that, if possible, a more important question than that of the assertion of the existence and presence of the Creator is at stake in such speculations as I have referred to. I believe that no intelligent man can think that the order of events in the history of the globe has occurred in the way of natural law, without the intervention of a creative mind, and at the same time retain the hope of a natural future life. It is difficult for us to believe in the natural origin of man, and at the same time retain the conviction which we have as Christians of a miraculous future. Surely the animal that grew from a monkey, which monkey had its origin in a lower type of life, that again proceeded from still lower forms, cannot hope to live beyond the time

when his perishable body shall return to
ments from whence it came. It, therefore,
to me that the retention of a belief in the
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inconsistent with these natural theories of li
the globe.

GEOLOGICAL GYMNASIUM.

1. Two lodes were discovered at the surface, 12 fath. apart, both underlaying north. The southernmost lode made an angle of $38^\circ\ 15'$, the other 23°. Required the depth at which these lodes will intersect.

2. From the foot of a perpendicular shaft, 70 fath. deep, a cross cut was driven south 14 fath. 3 ft. in length, where a lode was discovered underlaying north, and the angle of elevation $72^\circ\ 45'$. Required the length of this lode from the end of the drift or cross cut to the surface; also the distance from the brace of the downright shaft to the back of the lode at grass.

3. A shaft having been sunk 77 ft. on a lode, which made an angle of $34^\circ\ 45'$ it was there found that a slide had disjoined the lode, and carried it downward 40 ft. on an angle of depression of 59°; here the lode was again discovered and wrought 102 ft. on an angle of $42^\circ\ 15'$. Required the depth of the lowest point of the lode.

4. Let the true dip of a coal bed be I; and let it be required to insert the bed on a section which makes an angle ϕ with the plane of the dip; if i represent the required dip on the section, prove that it may be found by the relation

$$\tan i = \cos \phi \tan I.$$

5. What is the value of 16 tons 10 cwt. 2 qrs. of silver lead ore, the produce for lead being $8\frac{5}{12}$ in 20, and silver, $3\frac{7}{8}$ grs. from a 4 oz. avoirdupois sample; the price of lead £22 per ton, and silver, 5*s.* 3*d.* per oz., Troy; returning charges, £6 10*s.* per ton; and lord's dues one-twelfth for lead, and one-eighth for silver.

6. It is required to sink a perpendicular or downright shaft on the end of a level whose angles and drafts, measured from the engine shaft, are as follows:—

Drafts.	Lengths.	Bearings.
1	$53\frac{1}{2}$ ft.	S. 16° E.
2	23 "	S. 26 W.
3	58 "	S. 19 E.
4	$21\frac{1}{2}$ "	S. $34\frac{1}{2}$ W.
5	$53\frac{2}{3}$ "	S. $57\frac{1}{3}$ W.
6	30 "	S. $39\frac{1}{2}$ E.

Find the distance from the engine shaft in a straight lin end of the level; and also find the bearing of the end of tl from the engine shaft.

7. The back of a lode is laid open on the side of a hill, risi 16, and appears to bear W. 10° S., having an underlay of 2 per fathom. What is the true bearing or course of the loc

8. A shaft is sunk on a lode with the following incli and measurements:—

No.	Depth.	Underlay.
1	54 ft.	18°.45′ N.
2	42 "	12°.15′ N.
3	69 "	25° N.
4	96 "	7°.39′ S.

Find the average underlay of the lode per fathom; and a distance of the bottom of the shaft from the perpendicular

9. In estimating the value of a coal field in Northuml and Durham, it is usual to reduce the seam to cubic yard allow 3 of them to the Newcastle chaldron. What is th per cent. of this process, assuming the coal to weigh 78.12 l cubic foot, and the chaldron, 53 cwt.?

10. The depth of a colliery shaft is 260 yds., and the wo extend on a dip of 1 in 10 for 120 yds., when a slip dyke with, having an underlay of 1 in 6 towards the workings, downthrow of 40 yds.; the seam of coal is won beyond the and worked 240 yds. on the dip, which has changed to 1 in it were necessary to sink a shaft from the surface to the the workings, what is the depth to which it would hav sunk?

11. Let the true dip of a coal bed be 40°, and let it be requ insert the bed on a geological section, making an angle 27

the plane of the dip. Find the apparent dip to be entered on the section.

12. On 28th June, 1854, the following simultaneous barometric observations were made:—

Instruments.	Magnetical Observatory, Trinity College.	Two Rock Mountain.
Barometer (reduced).	29·665	27·834
Thermometer (air).	59°	$50\frac{1}{2}$°

Calculate the difference of level between the two stations.

13. Mention the principal ores of copper, lead, zinc, and tin. Write down their chemical formulæ, and their principal British and Irish localities.

14. Write down the six principal epochs of the globe recognised by geologists, together with the most important of their subdivisions, as found in England and Ireland.

15. Write out a list of the fossils characteristic of the Liassic period.

16. Given the time of occurrence of an earthquake at three points, find the velocity and direction of the earthquake wave.

17. What reason is there to believe that the violence of an earthquake movement is inversely proportional to the distance of the place from the origin of the earthquake?

18. Assuming the surface of the earth to be plane, show that the line joining the origin of the earthquake with the point of maximum *upsetting* effect on buildings, &c., makes an angle of 45° with the vertical.

19. Explain by vertical sections Mr. Darwin's theory of the three kinds of coral reefs, viz., Fringing, Barrier, and Atol.

20. Explain the principles by means of which the mean density of the Earth was found by Maskelyne and Cavendish.

21. Explain by means of a diagram Bischoff's theory of Volcanoes, and state the principal difficulties of this theory,

22. Write down your definition of

Phonolite,
Dolerite,
Diorite,
Basalt.

23. Give the names of at least six characteristic Devonian fossils, and mention the localities where they are usually found.

24. Mention the characteristic differences between the *Brachiopoda* and the *Conchifera*, and give the chief subdivisions of the latter.

25. State the facts which, in your opinion, are inconsistent with the theory of progressive developement of animal life on the surface of this planet.

26. Mention the names of any creatures which have become extinct within the historical period.

27. Draw an outline section of England, from London to Liverpool.

28. Draw an outline section from Brighton to the mouth of the Thames.

29. Draw a section from Cork to Limerick.

30. Mention the principal characteristic fossils of the Carboniferous Slate formation.

31. Mention the principal groups to which the vegetation of the Coal Period is referred.

32. What are Murchison's subdivisions of the Silurian deposits?

33. Mention the principal localities in England and Ireland where the Permian deposits are found.

34. What are the Crag formations of Norfolk or Suffolk?

35. What are Griffith's subdivisions of the Carboniferous deposits?

36. Describe the position of the Lias beds of England.

37. Define accurately the following rocks:—

Trappean Ash,
Syenite,
Protogene,
Hypersthene Rock.

38. What are the phenomena of Cleavage and Foliation of Rocks?

39. Mention the principal minerals developed in the Slate of Wicklow and Wexford, by the contact of the Granite of those districts.

40. What are the elementary minerals composing the Granites of Leinster and Ulster, respectively?

41. Describe the mode of occurrence of Tin, and its chief localities.

42. Mention the principal Ores of Copper, and some of their localities.

43. Describe the Mining operation known by the term "Stoping."

44. Enumerate the chief Lead and Copper Mines of Ireland.

45. State the mode of occurrence of China Clay, and the method by which it is prepared for market?

46. How do you account for the fact, that the levels of the Caspian and Dead Seas are below that of the Mediterranean?

47. Give an account of Sir Humphrey Davy's Chemical Theory of Volcanic Action.

48. Describe the subdivisions and give the formulæ of the Feldspar family; and state the rocks of which they are component parts.

49. Sounding at sea in a hundred fathoms water, in a particular locality, the bottom is found to be composed of large angular stones, mixed up with dead limpets and periwinkle shells. How does this result differ from what you would expect; and what geological changes does it indicate?

50. What is the character of the living and dead Mollusca, dredged from the deep depressions of the Scotch and North of England sea-bottoms? Mention the names of any such shells you are acquainted with.

51. State the arguments, geological or otherwise, in favour of the nebular hypothesis, and the objections which have been made to it.

52. State and prove the laws of climate, and apply them to the explanation of the following facts:—That the harbour of Hammerfest is clear of ice during the entire year; and that on the English and Scotch coasts, in January, there is the same temperature from Dover to the Shetland Islands.

53. Mention the principal families of the Mammalia, and the order in which they appeared on the earth.

54. To what class of Mollusca would you refer the Bellerophon of the Carboniferous period?

55. What is the Hippurite limestone? Describe its geological position, and the character of the fossils from which it derives its name.

56. Mention the principal genera of fossil Ferns of the Coal Period, and their generic distinctions.

57. Mention the *Stone Lilies* which characterize the several epochs of the history of the globe.

58. Mention some characteristic fossils of the Upper and Lower Silurian periods.

59. Draw a geological section from Dover to Beechy Head.

60. Draw a section from London to Crewe through the Trent Valley line.

61. What is the cause of the differences in the Deltas of the Nile, Ganges, and Mississippi?

62. How do you account for the Geysers of Iceland?

63. Define the following terms:—Crater of elevation; val-

ley of denudation; valley of elevation; dip; strike; heave throw; bedding; cleavage.

64. Define the terms:—underlay; hade; basset; stope; stulls; hanging and foot walls.

65. Explain, by means of a neat diagram, your idea of underhand and overhand stoping; and give the reasons for preferring the former, except in cases of necessity.

66. Describe fully the English method of working a copper or lead lode, and how it differs from the Saxon and Hungarian methods, respectively.

67. Mention the principal gangues which occur in metallic lodes.

68. Define the terms peach; gossan; cand; and explain the physical origin of gossan.

69. Mention the minerals in which copper occurs as a constituent; and state which of them are considered as ores of copper.

70. By what physical characters is the presence of silver or antimony usually inferred in galena?

71. Explain by a plan the "long wall" and "pillar and stall" working of a colliery.

72. What are the relative advantages and disadvantages of both systems? State the conditions of a colliery which would render it advisable to work on the "long wall" system.

73. A lode was opened on the back by costeening in several places, its course, by compass, found to be $10\frac{1}{2}^\circ$ S. of E.; but this was on the ascent of a steep hill, whose angle of elevation was $16\frac{1}{2}^\circ$, the lode underlaying northerly three feet in a perpendicular fathom:—

(*a.*) What is the true bearing of the lode?

(*b.*) What would be the amount of error in carrying on the line 600 fathoms (horizontal measure), supposing the run of the back of the lode had been taken, by mistake, instead of the true horizontal course?

74. In dialling a shaft sunk on a lode, it was found that the first draft measured 71 feet on an underlay of 14° 45′, but from that depth to the foot of the shaft proved to be 40° 15′ underlay, and the length 54 feet; required the position and depth of a downright shaft to take the lode at the lowest point.

75. Two lodes were observed 36 fathoms apart at the surface, bearing E. W.; of these the north lode was found underlaying south 18° 15′, and the south lode underlaying north 31° 45′; required the depth at which these lodes will intersect each other.

76. Of what formations is the *Posidonia Becheri* characteristic; and in what localities has it been found in Ireland?

77. Mention the names of some plants characteristic of the Oolitic and Carboniferous coal fields, respectively.

78. Of what formations are *Venericardia planicosta* and *Voluta athleta* characteristic? and state the natural families to which those Mollusca respectively belong.

79. Write a generic description or diagnosis of the Nautilus and Ammonites.

80. Describe the physical structure of the Wealden, and illustrate your description by a section.

81. Explain the manner in which the mean density of the earth has been found.

82. How would you decide on the age of a Tertiary formation?

83. State your reasons for believing, or not believing, Griffith's Yellow Sandstone to belong to the Lower Carboniferous strata.

84. Assign the geological position, and state the natural groups to which the following fossils belong:—

Calamopora Gothlandica,
Hamites spiniger,
Cheirotherium Barthi,
Megalodon cucullatus,
Apiocrinus rotundus.

85. Give a list of the characteristic Gasteropods and Conchifers of the London clay, and state your opinion as to the inference which may be fairly drawn from these shells as to the climatal conditions of the Lower Tertiary period in England.

86. What is your opinion as to the true characters and modern affinities of the following well-known fossils,

Pleurodictyum problematicum,
Turbinolia fungites?

87. Write down the subdivisions of the five divisions of the Animal Kingdom, viz.:—Vertebrata, Articulata, Mollusca, Radiata, Protozoa, in the order of their importance to the geologist.

88. Mention the four marine zones of life recognised by naturalists, and give examples of the Mollusca which inhabit each in the British seas.

89. What is Mr. Babbage's theory of the slow elevation and depression of land; and how does he apply it to the case of the Temple of Jupiter Serapis?

90. What is the verification proposed by M. Comte of Laplace's nebular hypothesis? Show the fallacy of it, and explain the cause of his mistake.

91. Draw a skeleton map of Asia, showing the principal mountain chains; and state what you know of their relative ages, as proved by fossil evidence, and by physical laws.

92. State the chemical composition of the following feld-spars:—

Anorthite,	Albite,
Labradorite,	Pericline,
Ryacolite,	Adularia,
Andesin,	Orthoclase.
Oligoclase,	

93. What are the physical characters and mineralogical composition of the following rocks:—

Trachytic Porphyry,	Basalt,
Trachyte,	Dolorite,
Andesite,	Diorite,
Obsidian,	Gabbro,
Pumice,	Serpentine Porphyry,
Pearlstone,	Protogene,
Trachytic Tuff,	Eurite?

94. Mention the best localities in Ireland for the study of the Secondary formations, and the peculiarities which distinguish these formations from the corresponding rocks in England.

95. Describe, in chronological order, the Tertiary formations of England and France.

96. Mention some of the characteristic Cephalopods of the Carboniferous epoch in Ireland.

97. Describe the beds composing the Wealden formation, and mention their chief localities in England.

98. Describe the Triassic system as developed in France and Germany; compare it with the corresponding formations of England and Ireland; and mention the names of some of its most characteristic fossils.

99. Mention the names of the principal Silurian and Devonian Corals, and state how far they are characteristic.

100. Describe the beds composing the Devonian formation in Germany, England, and Ireland; and state the opinions prevalent among geologists as to its connexion with the Carboniferous system.

101. Give a list of Cuvier's Orders of the Monodelphian Mammalia, and state which of them existed more abundantly than at present in former epochs.

102. What are the circumstances which would induce you to believe that certain coralline islands in the Pacific are undergoing depression, while others are rising from the ocean?

103. Mention the principal subdivisions of the Mollusca, spe-

cifying those Orders which were more developed in former periods than at present.

104. Define a Granite; and describe the principal varieties which exist in Leinster and Ulster.

105. Classify the varieties of lavas of existing Volcanoes, and compare them with the corresponding varieties of Trappean and Granite rocks.

106. What are the principal facts known by the name of Chemical Metamorphism of Rocks; and to what agencies do you believe them to be due?

107. Mention the various theories of Cleavage of Rocks that have been proposed, and give your reasons for preferring the mechanical theory.

108. What are the facts connected with volcanic explosions and eruptions that appear at variance with Sir Humphrey Davy's theory; and how, in your opinion, may these discrepancies be removed?

109. Describe and give examples of nodules occurring in Limestones, Dolomites, Shales, and Sandstones, and give your opinion as to their origin.

110. Define the following rocks, stating their mineralogical composition:—Hornblende Rock, Felstone, Pitchstone, Hornstone, Basalt, Trachyte, Serpentine, and Porphyry.

111. Classify the rocks of aqueous origin according to their mineral composition: specifying those which are of mechanical origin.

112. Describe the great Water-basins of North America, and mention the influences they have exercised in the developement of that Continent.

113. The theory of progressive developement in the creation of successive races is not supported by the facts known to us respecting the natural orders of Plants of the Carboniferous, Liassic, and Cretaceous periods?

114. State the order of developement of Fishes, mentioning the time of their first appearance; and show that this developement is not progressive.

115. Mention some of the facts adduced usually in support of Mr. Edward Forbes' Bipolar Theory of Creation.

116. Mention some of the most characteristic species of Euomphalus from the Carboniferous beds; and mention the secondary and recent genera to which it is allied.

117. What is the true character of the genus Bellerophon, and the nearest approach to it among living Mollusca.

118. What are the usual subdivisions of the Oolitic and Liassic beds of England?

119. What are Griffith's subdivisions of the Ca
of Ireland; and the base from which they procee
120. What are the proofs mentioned by Sir C
the length of time which elapsed during the d
Stone Lilies (*Apiocrinus rotundus*) of the Bradfor
121. Describe briefly the generic characters of
lites, Baculites, and Scaphites.
122. Write a description of the following Palæ
Orthoceras, Productus, Leptæna.
123. Mr. Sorby has discovered, in the physical
Magnesian Limestone of South Yorkshire, evidenc
Tidal currents; and in the structure of the upper
stone Grit of South Yorkshire, and North Derbyshi
continued action of a simple current. What is t
evidence in such cases, and what precautions sho
in making use of it?
124. What would be the character of similar e
port of the former existence of a shoal or coast lin
125. Mention the chief reasons, derived from t
fossils and microscopic structure of cleaved rocks,
Cleavage structure to be due to mechanical cau
polar forces or crystallization.
126. The following analysis represents the che
tion of a Felstone rock from the Co. of Kerry :—

Silica,	71.5
Alumina,	12.2
Peroxide of Iron,	3.16
Lime,	0.84
Magnesia,	0.39
Soda,	3.3
Potash,	5.65
Loss by ignition,	1.2
	98.3

Assuming that this rock is composed of Quartz,
Albite, calculate the relative proportions of each
127. What is the cause of Foliation in Metamo
the principal minerals developed by metamorphic
128. Explain clearly the principle on which t
of the Earth has been found by Mr. Airy's pendul
in Harton Coalpit.
129. Mention the principal varieties of Metamo

130. Mention the principal species of Felspars and Hornblendes that enter into the composition of Igneous rocks.

131. State the localities in Ireland where Basalt and Pitchstone occur.

132. State the laws of Cleavage and Distortion of fossils; and explain in general how they are accounted for on mechanical principles.

133. Give Bunsen's explanation of the phenomena of the Geysers of Iceland.

134. What are Laplace's arguments in support of the Nebular Hypothesis?

135. What is the cause of the efficiency of the Tide-wave as a transporting agent? How far has this been confirmed by the Atlantic soundings of the Submarine Telegraph?

136. A copper lode bearing E. N. E. with an underlay N. W. of 10° is heaved by a slide bearing N. 10° E. with an underlay of 40° S. E. In what direction should the underground workings be continued on the slide so as to regain the lost lode?

137. Assuming the preceding data, with the exception that the underlay of the slide is not given; with what amount of underlay in the slide will the miners' rule for finding the lost lode fail to give any assistance?

138. Explain the modes of searching for a lode known in Cornwall as Costeening and Shoding.

139. In drawing ore from a shaft 250 fathoms deep, by two ropes of the weight of 10 lbs. per fathom, each kibble weighs 120 lbs., and the load of ore is half a ton; at what point of the shaft will the whim begin to overrun the horses drawing it?

140. Give a general description of the method of developing a copper mine, as followed in England; including the shafts and pumps, with the mode of lowering the pump lifts down the shaft, the stoping of the mine, and the methods adopted for ventilation.

141. If a coalpit 1200 ft. deep be flooded by a feeder discharging 900 gallons per minute at the bottom, and if the united pumping engines be 400 H. P., which are in bad working order, and consequently only utilize 60 per cent. of their nominal H. P., it is required to find the additional engines that must be erected if the pit is to be kept dry.

142. An old coalpit, 600 ft. deep, and 10 ft. diameter, is full of water, and an engine of 80 H. P. is employed to unwater it; a feeder of 120 gallons per minute enters at the bottom of the pit, at a pressure equivalent to 150 ft. of water. Find how long it will take to empty the coalpit.

143. Describe the methods of working a colliery known as the

Post and Stall and *Long Wall* methods; and th
lating in each case.

144. What are the peculiarities of the venti
required in the North of England and in Staff
tively?

145. Describe the different kinds of bratticed s
Newcastle district; and the mode of winning th
the methods of tubbing the shaft in common use.

146. What are the peculiarities of the pumping
ham and Cornwall, respectively, and what has giv
State also the differences in the winding engine
of the two districts, and the causes of their pecul

147. The Cross from Van Diemen's Land
Mine bears 5° North of East, and at a distance
from the middle level of Glendalough Mine it th
branch bearing 15° North of East; the bearing o
in the middle level is 3° East of North. At wha
level will the north branch intersect it, the south
cross course appearing just at the mouth of the le

148. The celebrated Tin Carbona of the St. Ive
has a total length of 126 fathoms; its upper ext
78-fathom level of the Standard Lode, which
bears 35° North of East; the Carbona itself beari
West, and having its lower extremity situated at
fathoms below adit. Find the perpendicular di
Standard Lode at which a shaft should be sunk to
extremity of the Carbona.

149. An adit level is required to be driven (in t
Mine near Aue), to reach the bottom of the Stoll
tersect the Rosina and Red Andrew Lodes; the gr
the adit mouth to the Rosina Lode for a distance of
angle of 8° 30′; from the Rosina Lode to the Re
$4\frac{1}{2}$ fathoms; and from the Red Andrew Lode to t
Stoller shaft, 24 fathoms; the Rosina Lode has an
towards the adit mouth, and the Andrew Lode s
lay from the adit mouth. Find the lengths of a
to intersect the two lodes and engine shaft, respec

150. What are the usual mineral substances

152. The engine pit of Mostyn Colliery takes the 2-yard seam at the depth of 138 yds., and the chain pit intersects the same bed of coal at 84 yds. the distance between the pits being 91 yds.; the outcrop of the bed is 261 yds. from the engine pit, the rise in the ground being 29 yds. You are required from these data to ascertain whether there is any fault, and if so, to determine the amount of its upthrow or downthrow.

153. In the Nitshill Colliery, Renfrewshire, N. B., the upcast shaft is 135 fathoms, and the Victoria Pit, 175 fathoms in depth; the distance between the pits at grass is 687 yds. bearing 54° West of North; and the hade of the coal itself is to the South. Determine the inclination of the principal tramways of the mine.

154. Explain, by means of a diagram, the method of ventilating a colliery by means of a furnace provided with a *dumb drift.*

155. In the gravel of Clapham Common the following classes of stones are found:—

(*a.*) Angular flints, with edges slightly worn;
(*b.*) Flint pebbles, perfectly rounded;
(*c.*) Large pebbles of white quartz;
(*d.*) Pebbles of hard, compact, reddish sandstone;
(*e.*) Pebbles of porphyritic slate rock.
(*f.*) Subangular flattish fragments of a hard, light-coloured porous stone.
(*g.*) Fragments of brown, horny-looking flint.

Deduce as many geological inferences as you can from the occurrence and condition of these stones.

156. The following memoranda are extracted from my note book, and were made on the spot; what geological inferences may be deduced from them?

"April 16, 1858.—Levitstown Rath, gravel drift—Coarse limestone, 4 in. to 24 in. pebbles; occasional thin seams of fine gravel; rounded stones of brown crystalline dolomite; fine red sandstone; no slate, granite, or quartz."

N. B.—Bones of ox and horse, and a cinerary urn containing human bones, were found near the surface some months ago.

"Anderson's gravel pit—finer gravel, with clay bands; no granite, slate, or chalk flints; found red and green sandstones, and one stone of coarse, rounded grit (quartz and red sandstone) of angular fragments."

"Mr. Todd's quarry at Tankardstown.—Large angular drift, black limestone, with clay bands; small pebbles of red sandstone."

The localities mentioned above are on the River Barrow, halfway between Carlow and Athy.

157. Among the Mammalian remains of the drift grav London, the following have been found :—"An elephant horned rhinoceros; a large animal of the feline tribe, relate to the lion or the tiger; a large hippopotamus; a great bear midable hyena; the red deer; the reindeer; the wolf; an horse." What inferences as to climate would you draw fr collection of animals?

158. A fault is found in a cliff, making an angle of 56° horizon, and the angle of friction between the beds is sup be 30°; find the horizontal force which will produce a fault, compared with the weight of the displaced beds.

159. Find, in the same case, the horizontal force nece prevent a *direct* fault from taking place.

160. A massive horizontal bed of sandstone, 20 ft. thick, per cube ft., is acted on by a horizontal force; find the *an* the force in tons per linear foot of width of rock sufficient a fracture of the mass, and the *inclination* of this fractur horizon, supposing the natural angle of friction of the sa mass to be 35°.

161. State what you know respecting the mode of occu and your opinion as to the origin, of the felstone rocks of I Give also a list of the localities in which they have been

162. The pitchstone porphyry of Lough Eske, Co. D has the following composition :—

Silica, ...	64.04
Alumina, ...	10.40
Peroxide of Iron, . .	9.36
Lime, ...	4.24
Magnesia, ...	None.
Potash, ...	3.63
Soda, ...	2.91
Loss by ignition, . .	5.13
	99.71

Supposing this rock to be composed of quartz, orthocla stilbite, determine the relative quantities of each mineral.

163. State clearly the three laws of cleavage deduced fr distortion of fossils in cleaved rocks.

164. How does Mr. Prestwich explain the intermittent of the Bourne, near Croydon; and the Lavant in Sussex?

165. State the sources from which the Artesian wells don are supplied; the faults or dislocations which divide tiary beds in the neighbourhood of that city, and their effe the water supply; and contrast the Artesian wells of with those of Paris.

166. Two lodes intersect each other, and are found to be rich at their junction; I want to sink a shaft upon the line of intersection to take the vein at a given depth, and therefore require to know the bearing and underlay of the line of intersection. Find the bearing and underlay in the following case:—

1st Lode, N. 10° E. Underlay 75° E.
2nd Lode E. 15° N. „ 47° N.

167. In the Rammelsberg mine the *Gottlob Flacher* and the *Glückauf Spat* intersect each other with the following bearings and underlay:—*Glückauf Spat* E. 15° S., Underlay 50° S, *Gottlob Flacher*, S. 40° E., 80° S. W. Find the bearing and underlay of the intersection of these two lodes.

168. The course of a lode is found by compass to be E. 17° N. underlay 2 ft. per fathom, N. this course being measured on the back of the lode on the side of a hill rising 25° North. Find the true course of the lode.

169. It is required to sink a vertical shaft on the end of a level, and the diallings from the bottom of an old downright shaft are as follows:—

Drafts.	Bearings.	Lengths.		
		fath.	ft.	in.
1	$3\frac{3}{4}$° E. of N.	18	3	0
2	$5\frac{1}{2}$ N. of E.	12	1	6
3	8 S. of W.	15	4	0
4	28 E. of N.	4	5	3
5	$17\frac{3}{4}$ S. of E.	25	5	6

Find the point at which the new shaft must be sunk.

170. Describe the method by which the waste of an old colliery is approached at the boundary of a new pit.

171. In the Dawdon winning, County of Durham, at a depth of 73 fathoms, feeders amounting to 10,000 gallons per minute were broached in the quicksands. Find the engine power requisite to unwater the shaft.

172. Explain the following terms:—Horse gin; crabs for ground ropes; Jack gin; main crab; tail crab; shear legs.

173. If an engine make 25 strokes in drawing a "tub" or "kibble" to the top of a shaft 120 fathoms deep, and the thickness of the flat rope be 1 inch, what will be the diameter of the cage at the first lift?

174. At what point in a shaft will the ascending and descending kibbles meet, if the radius of the cage be 4 ft. the thickness of rope 1 in., and the depth of the shaft 1200 ft.?

175. Mention the distinguishing characters of *Turritella* and *Cerithium*.

176. What are the natural orders of the following fossil genera:—*Palæotherium*, *Oreadon*, *Glyptodon*, *Elephas*, and *Cervus*?

177. What beds in Ireland are characterized by the occurrence of *Posidonia;* and what are the speculations which have been made respecting the true character of this fossil?

178. What is the *Aptychus* of Solenhofen?

179. Distinguish the genera, *Ancyloceras*, *Orthoceras*, *Turrilites*, *Nautilus*, and *Ammonites*.

180. A rock has the following composition:—

Silica, ...	65.70
Alumina, ...	16.55
Peroxide of Iron, . .	0.55
Lime, ...	4.30
Magnesia, ...	0.60
Soda, ...	10.92
Potash, ...	0.25
Water, ...	0.10
	98.97

Supposing it to be composed of Albite and Pyroxene, how would you determine the relative proportions of the two minerals?

181. Describe the ocean currents which lie between the Gulf Stream and Europe.

182. Explain Mr. Sorby's theory of lamination in rocks of aqueous origin; and show the effect of a shoal upon the direction of the stratulæ.

183. Define symmetrical and unsymmetrical anticlinal axes, and show in what cases the latter will give rise to reversed faults.

184. Describe the geological action of waves, tidal and superficial, and show the mechanical principles on which your inferences depend.

185. Mention some of the most remarkable instances of the occurrence of fossil shells at great heights above the sea level.

186. What is meant by diagonal or cross stratification; and what evidence is it supposed to give of the former existence of tidal currents?

187. What are the true nature and zoological affinities of *Gaillonella* and *Bacillaria*?

188. Draw a sketch of the aperture of *Cerithium*, and state what you know of the habits of the recent species.

189. What evidence is there to show that nodular concretions were formed after the deposition and partial consolidation of the beds in which they occur?

190. Mention any remarkable instance that occurs to you of a great amount of depression of strata during any geological epoch.

191. How does Sir Charles Lyell account for the formation of *Sandpipes* in chalk; as at Eaton, near Norwich, and elsewhere.

192. There are only three known methods of determining the relative ages of stratified rocks? What are they?

193. What is the supposed amount of elevation per 100 years of the North Cape?

194. How do you account for the fact that, in recent Artesian borings made in the Deltas of the Po and of the Ganges, shells of recent species, with turf and forests, have been found 400 ft. below the present sea level?

195. How do you prove the existence of a Mammalian Fauna antecedent to the elevation of the Pyrenees, Alps, and Himalayas?

196. What are the localities in England in which mineral Phosphate of Lime is quarried; and what is its supposed origin?

197. What is the geological origin of the Trachytiform Mineral Phosphate of Lime, called by the American traders "Atlantic Guano Rock?"

198. What are the two best marked, and apparently most abrupt of the transitions from one geological epoch to another, which occur in the European strata?

199. What is the theory of Elie De Beaumont and Mr. Prestwich respecting the origin of the Woolwich and Blackheath shingle beds?

200. What is the difference between the genera of fossil ferns *Pecopteris* and *Neuropteris*?

201. What is the relation between *Lepidodendron* and *Lepidostrobus*; and what are their supposed recent affinities?

202. What are M. Adolphe Brongniart's views as to the botanical affinities of the *Calamites* of the coal beds?

203. What are A. Brongniart's reasons for referring the fern *Cyclopteris Hibernica* (Forbes) to the genus *Sphenopteris*?

204. What is Dr. Hooker's opinion as to the affinities of the *Sigillariæ*?

205. What are the true character and affinities of the *Sternbergia* of the coal measures?

206. What is the peculiarity in the dentit
Rat (*Hypsiprimnus*)?

207. How does the dentition of the fossil
found near Swanage, in the Purbeck Beds, d
Kangaroo Rat?

208. What are the zoological affinities
and the Phascolotherium?

209. State, as nearly as you can recollect t
per 1000 parts, of salts contained in sea wat

210. State your opinion on the theory of
would refer it to the action of sulphate of ma

211. Give some reasons for considering t
salt, worked as mines, as the result of tl
water.

212. Contrast the Silurian rocks north
Bay; and state the principal points on wl
opinion exists respecting them among geolog

213. State the views of the English and
Geology on the subject of the metamorphism

214. Describe the mode of occurrence of
masses, and explain the manner in which the
the quarrymen to detach large portions of roc

215. What are the relative thicknesses of t
the county of Limerick and the county of Kil

216. Draw a diagram section from Tullow
to Castlecomer, county of Kilkenny.

217. Draw a sketch of *Oldhamia antiqua*
spectively.

218. What is the geological position of *Po*
what is the lithological character of the rock
in Germany?

219. Under what circumstances may a *reve*
anticlinal axis?

220. Mention some of the shells usually
gravel of Howth.

221. Give Captain Molony's theory of the

222. What is the chemical formula of the A

226. Write a description of the genera Orthoceras and Ammonites.

227. What are the characteristic fossils of the Lias formation in Europe, and the natural families to which they belong?

228. Mention the characteristic fossils of the upper Silurian beds, and their natural families.

229. Mention some of the peculiar fossils which are found in the Devonian rocks, and not in either the Silurian or Carboniferous.

230. Give the natural orders and geological position of the following fossils:—

Phacops caudatus,
Baculites Faujasii,
Clymenia linearis,
Plicatula spinosa,
Belemnites pistilliformis.

231. State what you know respecting the Dinotherium.

232. Refer the following fossils to their natural order and geological positions:—

Pentamerus Knightii,
Ammonites Elizabethæ,
Ancyloceras Calloviensis,
Voluta Lamberti,
Cerithium giganteum.

233. What are the characteristic Brachiopoda of the Carboniferous beds in Ireland?

234. Give Agassiz' classification of fishes, and examples of each group, either recent or fossil.

235. Define the following terms:—

Dip,	Hypogene,
Strike,	Nodule,
Cleavage,	Ophite,
Joint,	Dolerite,
Geode,	Diorite.

236. Mention the localities in which Graptolites have been found in Ireland.

237. What are the mineral elements essential to the successful cultivation of wheat crops, and what are the geological conditions of soils likely to contain them?

238. How would you proceed to bring into cultivation a soil composed of stiff clay?

mention their relative advantages.

243. In the New Red Sandstone of England that there exists a certain relation between the per day that can be extracted from a well of ex diameter of the area it drains. If the well give per day, what is the nearest distance at which haustion can be sunk without injury to the w first well?

244. What is the nature of the material calle where is it obtained?

245. What is the mode of manufacture of tl made by Mr. Ransome of Ipswich?

246. What are the requisites of road metal mizing? Mention the kinds you have seen in t lin, and state your opinion as to their relati cheapness.

247. Describe the process of washing aurifero extracting gold from them.

248. Describe the mode of occurrence of sta in Cornwall, and the nature of the stream works county.

249. A vertical shaft in a coal district can through the same seam of coal—why?

250. If you were called upon to give eviden ciency of ventilation in a colliery in which an e curred, and were informed of the extent of the the number of men employed under ground, how ceed to determine whether there had been suffic ventilating the mine, or not?

liferous ores require for their developement the proximity of some of the igneous rocks.

255. What are the usual *rocks* that accompany lead and zinc ores, copper ores, native gold, and silver?

256. Mention some of the more common *minerals* that accompany lead and copper ores.

257. What are the French and German mining terms equivalent to our Gossan? Give a definition of a good and promising Gossan.

258. Under what circumstances is a rich deposit of ore expected in a part of a mine in Cornwall not yet reached by the underground workings?

259. An oblique shaft was found to measure 89 ft. 6 in. on an angle of 53° 15′; and it was also observed that the shaft had declined 3° 45′ W. from the intended right angle of the East and West lode. Required to find how far the shaft has departed from its true course.

260. What is the value of 74 tons 13 cwt. 2 qrs. of copper ore, the produce, by assay, being $7\frac{1}{8}$, and the standard £127 12*s*. 6*d*.?

261. Draw a figure illustrative of the contrivance known to coal miners as a dumb furnace.

262. Describe what is known of the arrangement of lines of greatest depth in the oceans of the globe.

263. Give a similar description of the law of arrangement of the lines of greatest elevation of land,—in mountain chains.

264. What are the geological effects of ice, considered as glacier and iceberg?

265. Compare Europe, Asia, Africa, and the Americas, with respect to their areas in relation to a given length of coast.

266. What are the peculiarities of ocean currents in the Mediterranean Sea; and how may they be accounted for?

267. Give a brief description of the physical geography of Persia and Beloochistan; and of their natural climate and productions.

268. The granite of Leinster may be regarded as a Quinary Granite; what are its component minerals, and their relative proportions?

269. What is the nature of the proof derived by Darwin, of the subsidence of the floor of the Pacific, from observation of the coral reefs of that ocean?

270. Etna, Teneriffe, and Erebus, present striking analogies with each other; what are they? How do these mountains differ from Cotopaxi, and how may the difference be explained?

271. What evidence have we of the presence of water in the formation of Granite, Clinkstone, and Basalt?

272. What are the various tests of age of strata, and what are their respective merits?

273. Fossils may be divided into various kinds, con merely as mineral substances. What are these divisio which of them are most commonly met with?

274. What are the chief subdivisions of the Lower Pal rocks in England?

275. What are the English divisions of the Jurassic roc the corresponding beds in Germany?

276. Write a general sketch of the history of fossil pl order of time.

277. What are the chief Brachiopoda characteristic of th boniferous Limestone?

278. What was the remarkable geological discovery ma Captain M'Clintock in Prince Patrick's Island, and whence its interest?

279. What are the principal coal fields of England and W Name them in some order, natural with respect to the physic graphy of the country.

280. The recent and fossil Echinodermata may be divide five groups. Name them, with their principal subdivisions

281. Write a brief history of Mammal life on the globe.

282. Explain the structures of rock indicated by the term *cretionary*, *prismatic*, *laminated*, and *porphyritic*.

283. Professor Tyndall recognises three varieties of structure in glacier ice, viz.,

1. Marginal structure,
2. Longitudinal structure,
3. Transverse structure.

Under what circumstances are these different structures loped?

284. Write a short description of the Valley of the Nil rain basin and cross section, explaining any peculiarities yo collect in it.

285. Write opposite the following names of fossils the they are characteristic of:—

1. Amplexus coralloides,
2. Voltzia heterophylla,
3. Trigonia alæformis,
4. Orthoceras laterale.

286. Give the names of at least four characteristic fossils c Lower Tertiary epoch.

287. Give a list of British geological formations, in order, below upwards.

288. Refer to their proper zoological and botanical classes and orders the following genera of fossils:—

1. Ammonite,	6. Cephalaspis,
2. Megatherium,	7. Neuropteris,
3. Cyathocrinus,	8. Pterichthys,
4. Lingula,	9. Pterodactylus,
5. Zamites,	10. Peuce.

289. Give a description of the ores, and mode of their occurrence, of the Valley of the Ovoca. State also the circumstances that give a peculiar and almost artificial value to the products of this mining district.

290. Mention the names of some of the chief tin mines of Cornwall, and describe the manner in which tin and copper sometimes occur in the same lode in that county.

291. Give a list of the principal metallic ores of copper found in lodes, stating what you know of their relative positions when found in the same lode.

292. What are the principal modes of leasing collieries, and which of them appears to you to be the fairest?

293. Give an account of "tribute" and "tut-work" in Cornwall and Wales, and of the various kinds of mining to which they are respectively suited.

294. Give a description, with diagram, of the Round Buddle of Cardiganshire.

295. Draw a vertical and transverse section, to illustrate the structure of the Palæozoic lamelliferous cup-shaped Corals.

296. Draw corresponding sections to illustrate the structure of the Neozoic lamelliferous cup-shaped Corals.

297. Mention some of the Carboniferous fossils that have retained their original colour-markings, and the inferences which have been drawn from this circumstance by naturalists.

298. What cases of false chambering of univalve shells occur to you; that is, chambering of shells not Cephalopoda?

299. What is the most common of the fish teeth found in the Carboniferous Limestone of Ireland?

300. The *Posidonia Becheri* is erroneously referred, by some geologists, to the Lower Carboniferous beds. On what facts is this reference founded, and how is it shown to be erroneous?

301. State what you know of the Bradford stone lilies, and of the inferences that may be drawn from their mode of occurrence.

302. Draw a sketch of the *Terebratula lyra*, and state its geological horizon.

303. Give D'Orbigny's classification of fossil Cephalopoda.

304. What is his classification of fossil Crustacea?

305. What are the differences in the structure of which distinguish the three species of elephant—two the mammoth?

306. What fossil bone is most commonly confound perienced observers with the human femur?

307. Give D'Orbigny's, or any other recognised of the Echinoderms.

308. What is D'Orbigny's classification of fossil B

309. Write an account of the alterations of climate, have taken place in Europe, from the commencement tiary Period to the present time; founding your argum evidence afforded by fossil Testacea and Mammalia.

310. Give an account of Sir Charles Lyell's theory mity in the physical and organic world; and state t physical geology which appear to you to be irreconci this theory.

311. Write an account of the differences, both physi ganic, between the chalk of the north and south of Eur North America; and draw from the facts any inference occur to you.

312. A Granite consists of 25 parts of Quartz, 65 o thoclase, and 10 parts of Mica, whose composition is—

Silica,	44.27
Alumina,	35.52
Lime,	0.82
Magnesia,	0.92
Potash,	11.01
Soda,	0.90
Water, &c.,	6.56
	100.00

Determine from these data the chemical composition o nite.

313. The chemical composition of a Granite is—

Silica,	70.82
Alumina,	16.08
Lime,	2.65
Magnesia,	0.31
Potash,	4.64
Soda,	2.31
Water, &c.,	3.19
	100.00

Supposing this rock to be composed of Quartz, Mica as before, and an unknown felspar, of formula

$$RO, SiO_3 + Q_2O_3, 3SiO_3,$$

find the chemical composition of this felspar.

314. The Syenite of Carlingford is composed of Anorthite and Hornblende, the chemical composition of which is as follows:—

HORNBLENDE.

Silica,	50.72
Alumina,	9.36
Protoxide of Iron,	18.61
Lime,	16.96
Magnesia,	2.40
Loss by ignition,	1.52
	99.57

ANORTHITE.

Silica,	45.87
Alumina,	34.73
Lime,	17.10
Magnesia,	1.55
	99.25

The Syenite itself has the composition—

SYENITE.

Silica,	47.52
Alumina,	28.56
Protoxide of Iron,	7.23
Lime,	15.44
Magnesia,	1·48
	100.23

Find the percentages of the two minerals in this Syenite.

315. Give an account of Durocher's statement, "that all igneous rocks, modern and ancient, were produced by two Magmas, which coexist below the solid crust of the globe, and occupy there each a definite position."

317. Give some examples to prove that rocks
chemical composition may occasionally differ cc
neral composition. To what cause do you attri
318. What is Durocher's classification of Gra:
319. Classification of Trachytes?
320. What is the classification of the Basic r(
321. How does he group the rocks intermedia
tween his two extreme types?
322. What is the character of the changes tha
in the composition of Igneous rocks, from the
deposits to the present time?
323. What circumstances, chemical and phys
able to the developement, or absence, of the twc
324. What are the characters common to th
whether Siliceous or Basic?
325. What are the Felspars present in the
rocks, respectively.
326. Describe briefly M. Gages' chemico-mecl
analysis of rocks, and give the results he obtain
to the fibrous Dolomite of Miask.
327. What is the information afforded by thi
lysis with respect to the serpentines?
328. What are the pebbles and stones usually
Red Conglomerate in Ireland?
329. What are the additions made to our k
Cambrian fossils of Bray Head and Howth by
Professor Kinahan?

335. What is the composition of rock-salt? With what deposits is it usually associated? What is its probable origin?

336. Classify the rocks of aqueous or mechanical origin, and state the sources from which they are derived.

337. Give an account, with rough section, of the structure of a volcanic cone. What is meant by craters of elevation and eruption?

338. Describe the principal phenomena that accompany an earthquake, and give some account of their causes.

339. Define the following terms:—Dip, strike, outcrop, outlier, anticlinal and synclinal axes.

340. How do the following metals occur in nature, and in what ores:—Lead, gold, tin, platinum?

341. What is the cause of the great masses of conglomerate found in certain geological deposits? How are they connected with the history of life on the globe?

342. Give the divisions and subdivisions of the principal systems of rocks.

343. State what you know of the fossils found in the Cambrian rocks.

344. What are the natural affinities in the living creation of the following groups ot Silurian fossils:—Cystideans, Crinoids, Graptolites, Trilobites?

345. The Silurian rocks may be characterized by the *presence*, and also by the *absence* of remarkable groups of fossils.

346. What are the subdivisions, from below upwards, of the Carboniferous rocks in Ireland and Scotland, respectively? What information does the order of these rocks give as to the physical history of the period in the two countries?

347. The Carboniferous periods in Scotland and Ireland differ widely in organic remains?

348. Give some account of the Flora of the Coal period, and of the groups of living plants most nearly allied to those of that period.

349. Give the divisions and subdivisions of the Secondary rocks in England and Europe.

350. Give some account of the geological distribution of the remains of Mammals.

351. What was the order of developement of Fishes in the history of the globe?

352. What are the chief geological features of the lower, middle, and upper Tertiary periods? Where are they best exhibited?

353. Give some account of the geological peculiarities, physical and organic, of the Post-Tertiary period, with special relation to the gravels and drift fossils of Ireland.

354. Three borings are made, at the corners of an equilateral triangle. on the surface of a horizontal country; these borings

356. Given the map of a property, in whic
exist; explain how you would determine th
bed; and state where you would recommend
shaft.

357. What is the coalminer's rule called tl
shaped outcrop?" and give the explanation o

358. Draw a rough plan of Coed Talon Mine,
the following description:—

1. There are two shafts close together.
2. Three *levels* are extended from the sl
   a. The principal horse road;
   b. A dip level for water and air wa
   c. A rise level, the thick pillars o
   horse way from the pressure of th
3. *Witchets* (or boards), are driven out
   6 yards wide, and are *holed* into eacl
   tions of similar width, leaving tl
   square.
4. Three *drifts* are extended to the ris
   the same principle as the levels alr

359. If an engine make 16 strokes in drawi
surface from a shaft, the depth of which is 80 f
ropes not lying on each other; what must be
flat rope cage, so constructed that the engine n
number of strokes as before, the thickness of the

360. The "Stamps" at Polberro are worke
rate:—

361. Define the following mining terms:—Shafts, winzes, stopes, levels, crosscuts.

362. What are the chief minerals and substances found in lodes in connexion with metallic ores?

363. Classify the ores of Copper *geologically*, and state their mode of occurrence in a mine.

364. What are the ores of Nickel, and where are they found in Great Britain?

365. What are the principal ores of Manganese? How is their commercial value determined?

E. gr.—"Manganese guaranteed 60 per cent. f. o. b., Liverpool, at 60*s.* per ton."

What is the meaning of this statement?

366. It is required to sink a vertical shaft on the end of a level, and the diallings from the bottom of an old downright shaft are as follows:—

Surveyed with a Right-hand Dial.

	Length.		
No. 1.—$356\frac{1}{4}°$, ...	18 fm.	3 ft.	0 in.
„ 2.— $84\frac{1}{2}$, ...	12	1	6
„ 3.— 98, ...	15	4	0
„ 4.—A winze, 322°; underlay, $25\frac{1}{2}°$; inclined length, .	11	2	0
„ 5.—$107\frac{3}{4}$, ...	25	5	6
		End.	

You are required to enter the results of your calculation in the following form:—

No.	East.	West.	North.	South.
1				
2				
3				
4				
5				

367. The Mammalia have been divided into M
Didelphian; what objections are there to this di

368. What are the characters that distinguish the Quadrumana?

369. What is the difference, in dentition, betw mana of the old and new worlds?

370. Mention some of the most remarkable o Carnivora found fossil in Britain.

371. What is Cuvier's characteristic mark of th

372. What are Cuvier's divisions of Digitigra

373. Mention the names of any fossil Rodent you.

374. What are D'Orbigny's divisions of the E

375. Mention the principal fossil Edentata th therto found; and state the locality and formati occur.

376. Refer to their proper families the follow malia:—

(a). Dinotherium giganteum,
(h). Elephas primigenius,
(c). Anoplotherium commune.

377. Supposing the Monodelphian and Didelp to form parallel groups, what corresponds to the the Didelphians?

378. Which of the Cuvierian Orders of Mamn developed in geological epochs than at present?

379. What are the true affinities of the Bryozoa

380. Mention some of the Carboniferous Bryoz

381. What are D'Orbigny's subdivisions of the

382. What is the zoological position of the sils:—

(a). Nummulites nummularia,
(b). Graptolithus priscus,
(c). Voluta Lamberti?

387. Mention some proofs derived from the existence of fossils of the high temperature of the globe during the Oolitic and Liassic periods.

388. What facts connected with the successive appearance of Fishes on the globe are inconsistent with the supposition of progressive developement?

389. Refer to their geological position the following fossils:—

(*a*). Spirifer Walcotii,
(*b*). Spirifer rotundatus,
(*c*). Spirifer glaber,
(*d*). Terebratula digona.

390. Write a description of any univalve fossil with which you are acquainted.

391. What is the essential difference between the *Euomphalus Reginæ* and *E. rotundatus*?

E. Reginæ—Testâ conicâ; spiræ angulo 70°; anfractibus 6–8, transversim eleganter striatis, sinu lato carinatis, suprà tabulatis; aperturâ subquadratâ, scissurâ altâ superne denotatâ.

Breadth : Height = 150 : 100.

392. To what living group of Crustaceans were the Trilobites most closely allied?

393. Write a description of the genus *Trinucleus*.

394. Write a description of the genus *Ogygia*.

395. What is the number of rings in the thorax of *Calymene*; and what peculiarity distinguishes its buckler?

396. Write a description of the genus *Ampyx*.

397. What are the principal Trilobites found at Pomeroy, county of Tyrone?

398. What are the Crustaceans found in the coal shales of the counties of Carlow and Kilkenny?

399. A fragment of a remarkable Crustacean has been found at Kiltorcan, county of Kilkenny—what light does it throw on the relations between the Lower Carboniferous beds of Scotland and Ireland?

400. What are the three Laws of Distortion of Fossils produced by cleavage, observed by Professor Haughton?

401. What are Mr. Sharpe's Laws of Cleavage; and how far do they agree with those observed by Professor Haughton?

402. Define the "distortion of a fossil."

403. If ϕ denote the angle between the planes of bedding and

cleavage, and Δ the distortion of a fossil, and it be ex
follows—

$$\Delta = \sqrt{P\sin^2\phi + Q\cos^2\phi},$$

what relation exists between P and Q?

404. What is your definition of the following terms :- age," "Joint," "Fault?"

405. What facts seem to show that cleavage took vious to the consolidation of the rock mass, and joir sequently?

406. What was Professor Tyndall's experiment to illu mechanical cause of cleavage?

407. What is Mr. Sorby's theory to explain the origi cleavage?

408. What is the meaning of Professor Rogers' "F arrangement of cleavage planes in mountain masses?"

409. What is the bedding of the cleavage planes of th the South of Ireland; and what is its relation to the b their planes of bedding?

410. State briefly the arguments in favour of Laplac lar Theory of the origin of the Solar System, and the a against it.

411. State Humboldt's laws of climate, and give sor nation of them, founded on the general meteorolog globe.

412. An earthquake shock is felt at given times at *thr* find the direction and horizontal velocity of the Wav supposing the earthquake to be plane.

413. If the wave be spherical, and not plane, given th shock at *four* towns; show how the centre of the earthq wave velocity may be found.

414. During the passage of an earthquake shock, the church tower, b feet in height, is thrown off and falls tance of a feet horizontally from its former position; d the horizontal velocity of the *shock*.

415. Give an approximation to the thickness of the A læozoic, Mesozoic, and Cainozoic strata, as developed i and North America.

416. Mention some of the most important of the Met rocks, and the minerals that characterize them.

417. Define the terms :—Dip, strike, fault, foliation, a age.

418. Give a list of the beds composing the English rocks.

419. Give a similar list of the beds composing the English Oolitic rocks.

420. State Cuvier's classification of Mammalia, specifying those groups which occurred most abundantly in former periods, and the localities in which their fossil remains are found.

421. Mention some (at least ten) of the fossils characteristic of the Carboniferous Limestone of Ireland.

422. Refer the following fossils to their place in the geological and zoological scales:—

Dinotherium,
Voluta Lamberti,
Plagiostoma giganteum,
Turrilites costatus.

423. Give an account of the Flora of the Coal period, referring the various groups of plants to the natural orders, now living, which most nearly resemble them.

424. Mention the Crinoida most characteristic of the successive ages of the globe.

425. What are the fossils commonly found in the black calcareous shale between Balbriggan and Rush; and what is the geological position of that shale?

426. Mention the principal fossils found in the Cambrian rocks of Bray Head, and the mode of their occurrence, as explained by Dr. Kinahan.

427. What is the chemical composition and mineralogical formula of the Calamine found at Silvermines, Co. Tipperary?

428. Give an account, geological and zoological, of the Chitonidæ, and of the species found in the Carboniferous rocks of Ireland.

429. A rock is met with in field work: it has a soapy feel, greenish colour, and appears doubtfully bedded; it would on a casual examination be pronounced to be serpentinous; this determination might be very erroneous; show this by examples, and pointing out the group of rocks to which it might be most closely related.

430. What are the Permian localities of Ireland?

431. Write a description of the *Pentephyllum Adarense*.

432. Describe the mode of occurrence of rock salt, and the minerals associated with it; its geological origin; and the best method of working it.

433. Describe the modes in which iron ores occur; the kinds of ore found in each case; and the method of working them.

434. Describe the manner in which you would set about the winning and working of a deep coal bed, lying under a given mining sett.

wall, hucan, flat-rods, fork.

438. Mention the chief ores of copper; and de
in which they are commonly supposed to have l
into the lode.

439. A shaft having been sunk on a lode 114 f
of 54° 30′, at this place the lode was separated,
a slide 32 ft., the angle of elevation being 47°; h
again cut, and prosecuted on an angle of 51° f
73 ft.; it is required to find the distance from th
point where a shaft should be sunk to take the lo
the previous sinking.

440. Borings are made at angles A, B, C, of a
sides are *a*, *b*, *c*; and a coal bed pierced at depth
press the inclination of the coal bed to the surfac

441. Describe the "round buddle" used in the
ores in Cardiganshire.

442. It is commonly believed by geologists tha
the Northern Hemisphere, or at least of Europ
different from what it now is. Mention the pro
position commonly adduced, and founded on the c

(*a*.) The fossils of the Italian Strata;
(*b*.) The extinct quadrupeds of Europe and
(*c*.) The fossils of the Arctic Regions.

443. To account for these changes of climate, v
astronomical and otherwise, have been invented
account of the following, and state your opinion o

445. Many theories have been invented which seem to explain this developement of life, as well as other facts well known to naturalists. State the theories of the following speculators:—

(*a.*) Linnæus;
(*b.*) Buffon;
(*c.*) Lamarck;
(*d.*) Author of the "Vestiges of Natural History of Creation;"
(*e.*) Gosse;
(*f.*) Darwin;

pointing out precisely the points of difference in the theories of Lamarck, the "Vestiges," and Darwin.

446. Mention in order the Palæozoic rocks of Ireland, with the names of some localities in which they are respectively well developed, and the names of some of their more important fossils.

447. Mention in order the Jurassic and Cretaceous rocks of England; the names of localities celebrated for their respective occurrence; and the names of their chief characteristic fossils.

448. Give as detailed a description as you can of the various classes of Plants found in the coal measures; and state what you know of their probable recent affinities.

449. Give Cuvier's classification of the Mammalia; adding a fossil example of each Order, and the locality in which it has been found.

450. What are the peculiarities of the mechanism of the skeleton of the Reptiles, with respect to the following particulars:—

(*a.*) The articulation of the mandible, or inferior maxillary to the skull;
(*b*). The articulation of the skull to the spinal column;
(*c*). The shoulder joint of the *Sauria;*
(*d.*) The vertebral articulation of the *Chelonia.*

451. Describe the structure of the *Brachiopoda*, and give a series of these shells, characteristic of each formation, from the oldest Silurian down to the present time.

452. Give a detailed account of M. Durocher's system of Petrology.

453. What is Durocher's classification of the Siliceous, Intermediate, and Basic Igneous rocks?

454. What is Durocher's classification of the Palæopyric, Mesopyric, and Neopyric rocks?

455. A granite is composed wholly of quartz and pu goclase in the following proportions:—

Quartz, . . .	25 per cent.
Oligoclase, . .	75 ,,
	100

Write down its chemical composition.

456. Solve the same lithological problem, using pure alb stead of oligoclase.

457. Give an account of the phenomena accompanyi earthquake, according to Mr. Mallet.

458. How may the surface direction and velocity of an quake wave be determined from observations on the times shock at different places?

459. The velocity and elevation of the molecular shocl be found from observations made on church bells, copir walls, &c., projected from their original positions. Explair how this is done.

460. Illustrate, by means of a rough section, the successi strata at the Tower of Hook, county of Wexford, and the lations with the corresponding beds of the county of Wate at Dunmore East.

461. Mention the most important facts discovered by the exploring expeditions, from 1848 to 1858, respecting the C niferous, Silurian, and Liassic fossils of the Arctic regions.

462. Describe the *Corynepteris stellata* of Baily, and me the localities in which it has been found.

463. Give a general description of the lodes found at S mines, county of Tipperary; and the geological conditions which they occur.

464. Give a description, with diagrams, of the method of ing a coal shaft most usual in the north of England, incl the "tubbing."

465. If consulted as a mining engineer, on the following how would you advise the owners of Heaton Colliery?

"About the year 1812, the workings of the High Main at Gosforth, near Newcastle, had gradually progressed till approached the Ouseburn, which divided them from the co of Heaton, lying to the dip. Underneath the burn was res an imperfect barrier of coal, which in ancient times had perforated in many parts, by which means the two collieries placed in intercommunity.

"Messrs. Brandling, the owners of the rise colliery of Gosf prepared to work away the pillars of coal underneath their

tion of the burn, which alarmed the owners of the dip colliery; and they, therefore, served them with a notice, threatening to hold them responsible, if they ventured to remove coal which would inevitably bring down the waters of the rivulet; and, as such influx could not by possibility be stopped, it would, beyond doubt, overpower the engines of Heaton."

466. Mention the most important ores of Copper found in Cornwall and Saxony, respectively.

467. What are the chief localities in which Tin ore is found?

468. Describe, briefly, the principal causes that modify the earth's surface, dividing them into atmospheric, aqueous, and igneous causes.

469. Name the principal minerals that enter into the composisition of the most common and important eruptive rocks.

470. Give some account of the general character of the Metamorphic rocks, and of the relations between them and the Plutonic rocks.

471. Mention some of the most common of the mineral substances found in veins worked as mines for the metallic ores they contain.

472. What is the nature of fossils, and their value with reference to the divisions of rocks into periods? Contrast this use of fossils with the corresponding use of the mineral character of the rocks in which the fossils are found.

473. Give the leading subdivisions of the Silurian rocks, as observed in Wales and England.

474. Give some account of the Devonian rocks of Devonshire, Herefordshire, and the South of Ireland, of the difference of their fossils, and lithological character.

475. Mention some of the Devonian fossils which are not found either in the Carboniferous or Silurian rocks.

476. Write down the subdivisions of the Carboniferous rocks of England and Wales, and the corresponding rocks of Ireland.

477. Coals may be divided into the bituminous (or hydrogenous) and anthracite; classify the coals of England, Wales, and Ireland, according to this division.

478. Mention the chief peculiarities of the Permian system, as developed in England and the other parts of Europe.

479. The Trias system differs in its developement in England and Germany; what does the difference consist in, and how has its peculiar developement in England led to difficulty in studying it?

480. Give the subdivisions of the Jurassic system in England, including the Wealden beds.

481. In what beds were the earliest Mammalian remains discovered; what group did they belong to?

482. Mention the names of some of the most important building stones of the Permian and Jurassic rocks.

483. In what formations has coal been discovered, and in what countries?

484. Mention some of the fossils found in the Hastings sand, and the inferences which may be drawn from their occurrence.

485. Give the subdivisions of the Cretaceous system in England and Europe.

486. What are the principal Tertiary beds of England and France, and their relative ages?

487. What is boulder drift; and what is the evidence on which the geological theory of its origin has been based?

488. What are the least percentages of iron, lead, zinc, copper, silver, and gold, that are worth extracting from ores of these metals?

489. The contents of mineral veins are due, partly to influences from above, and partly from below; how is this proved by geologists?

490. Define the terms:—

Hanging and Foot Walls,
Country,
Saalband,
Back of lode,
Underlie of lode.

491. Mention the principal "gangues" of mineral veins; dividing them into sterile and fertile.

492. The owner of a coal sett, surrounded by other mines at work, consults you as to the barriers he should leave at the boundaries of his sett; what should you take into consideration in giving your advice as an engineer on this point?

493. Name the most important characteristic fossil plants of the Coal period.

494. Name the principal characteristic fossils of the London Clay.

495. Of the rain that falls on a given rain-basin, a part is evaporated, a part is consumed by vegetation, a part flows directly into the river bed, and a part sinks into the ground. State what you know of the relative proportions of these different portions of the rain fall.

496. What is the oldest fossil remain of Fishes known to geologists?

497. Describe the *Chorda piscium dorsalis*, and its relations to the hæmal and neural arches.

498. What is the difference between the *Ichthyodorulith* of the bony and cartilaginous Fishes?

499. Give Agassiz' and Müller's classification of Fishes, and state how many of Müller's groups are found fossil.

500. What are the three great divisions of the *Pisces plagiostomi?*

501. Describe the dentition of the Port Jackson shark, and name some of the most remarkable fossil Fishes which are supposed to have had a similar dentition.

502. Define the terms *placoganoid*, *lepidoganoid*, *heterocercal*, and *notochordal*.

503. Discuss the question of the relative superiority in organization of the ancient and modern Fishes.

504. Describe the *Hippurites* and *Diceras*.

505. What are the opinions of geologists as to the zoological position of *Maclurea* and *Ecculiomphalus?*

506. Very different opinions have been put forward as to the true zoological position of the remarkable fossil, *Aptychus*, of the Solenhofen beds?

507. Distinguish the Nautilidæ from the Ammonitidæ, and describe their mode of walking on the sea bottom.

508. A remarkable law of developement of life is illustrated by the fossil Fishes, and by the fossil tetrabranchiate Cephalopods?

509. Describe the dentition of *Amphitherium Prevostii*.

510. What is the probable zoological position of *Amphitherium* and *Plagiaulax?*

511. Give the dental characters of the Ruminantia.

512. What was the zoological position of *Zeuglodon*, *Phocodon*, *Dinotherium*, and *Megatherium?*

513. What are the characters of the toe bone of the Edentata, on which Cuvier founded his announcement of the former existence of this order in Europe, from an examination of a single bone?

514. What reasons are there for believing that the Reindeer is the nearest approach among living animals to the "Irish Elk?"

515. Describe the "sectorial" teeth of the Carnivora.

516. Define the following terms, used by Werner:—

Stockwerk,
Stehenderstock,
Schwärmer,
Salhband.

517. Define the following terms, used by French miners:—

Allure,
Gangue,
Matrice,
Druse,
Craque,
Mur et toit.

519. If an argentiferous galena contain ... silver in 200 grs. of ore, how many ounces Tr... lead contain?

520. State briefly Werner's reasons for consi... strictly analogous to fissures in the surface of th...

521. By what analogies does Fournet account... of veins of quartz, felspar, garnet, and tourmalin... taining tourmaline and garnet occasionally?

522. If the following subterranean survey is ... strument having 23° W. variation, and plotted ... true meridian, without being reduced thereto, ... magnitude of the error produced, or distance bet... the two plottings,

1.	S. 30° W.	4
2.	F. 50 W.	8
3.	N. 50 E.	9
4.	N. 55 W.	8

523. In a coal mine the following survey w... tered in the survey book:—

Bearing.	Distance.	Angle of I...
	Chains.	
N. 10° W.	5.00	30° decli...

524. Convert the following observations into Bearings, referred to the meridian—first, on the supposition that they were made with a right-hand dial; and, secondly, with a left-hand dial.

Observations.	Right Hand.	Left Hand.
$201\frac{1}{4}°$		
$176\frac{1}{4}$		
$305\frac{3}{4}$		
$28\frac{1}{2}$		
$107\frac{1}{8}$		
$97\frac{3}{4}$		
348		

525. Mention the most important localities in the United Kingdom for the occurrence of steatite; and some of the uses to which this mineral is applied.

526. Give the physical and blowpipe characters of carbonate of strontian and carbonate of barytes.

527. Give an account of Dr. A. Smith's method of estimating, by the blowpipe alone, the quantity of water in an earthy mineral.

528. Distinguish, by the blowpipe, between magnetic and common pyrites.

529. What are the blowpipe characters of apatite?

530. To what order of the class Pisces do the Devonian Fishes belong, and what are the most remarkable genera among them?

531. In what formations have Mammalian remains been discovered? How do the Pleistocene and Eocene Mammalia differ?

532. What are the most striking peculiarities in the structure of the genera Ichthyosaurus, Plesiosaurus, and Pterodactylus?

533. What is a Belemnite? Give an account of the structure and zoological relations of the animal to which it belonged.

534. What are the bone caves of Germany, England, and Ireland? When, and by what animals, were they inhabited? How did they pass into their present state?

535. The Igneous rocks are divided by M. Roth into—Orthoclasic, Oligoclasic, Labradoritic, and Anorthitic.

Refer the following rocks to their natural families in this arrangement:—

Trachyte,
Eukrite,
Gabbro,
Granite,
Greenstone.

536. Describe the methods of Archimedes, Delesse, and Haughton, for finding the percentage of constituent minerals in a given rock; and mention the objections to each of these methods.

537. How do you distinguish, by the eye, without the aid of Crystallography, the Anorthic from the Orthic felspars?

538. Give a description of the characters of the *Crinoidea*, *Asteroidea*, and *Echinoidea*.

539. What are the subdivisions of the Cephalopoda recognised by Professor Owen? Give a short sketch of the geological history of each.

540. To what suborder do the *Palæoniscidæ* and *Caturidæ* belong? Describe the characters of the families.

541. What are the characters that distinguish the *Enaliosauria* from other Reptiles?

542. Describe the *Ichthyosaurus* and *Plesiosaurus*; showing the principal characters by which they differ from each other; and also the characters by which they are connected with Mammals, Fishes, and Saurians.

543. Describe the principal fossil *Cervidæ* found in Ireland; and state the inferences which may be drawn from the occurrence of these fossils.

544. What are the physiological characters by which the Marsupials are distinguished from the other Mammals? Mention some of the most important of the fossil Marsupials, and the subgroups to which they belong.

545. Describe the Pterygotus, and state what you know respecting the homologies of its various parts.

546. Describe the relations between the solid mass of the globe and the water that partially covers it; stating accurately the shape of each; and giving the chief laws that regulate the shape of the great masses of land visible above the water.

547. Discuss the problem of the supply and discharge of water in the Mediterranean Sea; stating the conclusions arrived at by Lyell and Herschel, and your reasons for agreeing with either.

548. Describe the circulation of the atmosphere, according to the views of Maury and Herschel; pointing out the differences in their views; and give an account of the dynamical causes producing this circulation, and state which of these causes, in your opinion, is the most efficacious.

549. Give a similar account of the circulation of the ocean, and of the causes producing it, according to Maury and Herschel.

550. What is Herschel's account of the origin of foliation and cleavage in the argillaceous rocks, and of the connexion between these two kinds of structure?

551. Give Herschel's account of the cause of the "rainless districts;" and draw a sketch map of Africa and of South America to illustrate this theory.

552. Describe the "rainless districts" of the globe, and state the mineral productions found in them in consequence of the want of rain.

553. Give Maury's theory, with illustrations from rivers, to account for the fact that more rain falls in the Northern than in the Southern Hemisphere.

554. How do you account for the remarkable fact, that 88 inches of rain fall each year at Sitka and Bergen, while the rainfall at Uleaborg is only 13 inches, and at Petersburgh only 17 inches?

555. The granite rocks of Donegal, Aberdeen, Sweden, and Finland, are superior to those of Cornwall, Leinster, and Mourne, in their power of resisting the action of the weather; how is this fact ascertained, and to what circumstance is it attributable?

556. Describe the "cloud-ring" of the earth, the equatorial "doldrums," and the "horse latitudes;" and show the relation of these to the distribution of the mean pressure of the atmosphere, and the direction of the prevailing winds in different latitudes.

557. The following observations were made on board a yacht, on the 14th July, 1862, off the Naze of Norway, during a stiff breeze:—

Direction of scud of clouds, . . .	S. S. W.
Direction of yacht's burgee, . .	S. by E.
Bearing of yacht's course, . . .	E. S. E.
Yacht's rate by log, ...	11 knots per hour.

Calculate, from these data, the velocity of the wind.

558. Describe the Gulf Stream, and discuss the various theories that have been advanced to account for it, and also its effects upon the climate of Europe.

559. Give some examples of the law of distribution of animals by representative types; taking your cases from the Carnivora, Ruminantia, and Grallatores.

560. Compare the present geographical distribution of Mammals with that which prevailed on the earth during the Tertiary and Quaternary periods.

561. A milk-white mineral scratches the knife, is infusible before the blowpipe, and dissolves readily in carbonate of soda. What is it?

562. What is the mineral that exhibits the following blowpipe reactions:—

"Yields easily to the knife; nearly as hard as calc-spar; does not fuse in the flame of a candle; on charcoal fuses readily into a very fluid colourless globule, which becomes white and opaque

563. What mineral has the following blow
"Does not effervesce with acids. Dec
tinges the flame behind the assay greenish-ye
a white enamel. No water. With borax d
nued effervescence."

To what cause would you attribute this conti

564. It is required to sink a perpendicular
a level, whose bearings and drafts measured a

No.	Draft.			Bearings.	Northing. D cos φ.	Southin D cos φ
	Fms.	Ft.	In.			
1	8	5	6	16° 30′ E. of S.		
2	3	4	11	26 0 W. of S.		
3	9	4	0	19 0 E. of S.		
4	3	3	6	34 30 W. of S.		
5	8	5	8	57 30 W. of S.		
6	4	5	10	39 30 E. of S.		

Find the distance and bearing of the point at
of the shaft should be commenced.

565. In dialling a shaft sunk on a lode, it
first draft and the second draft measured as fol

No.	Draft.	Underlay.	D cos u

566. What were Werner's principal divisions of rocks? Show that the geologist is not justified in assuming any existing rocks to be those which originally constituted the solid part of the earth.

567. Show that the climate of Europe has, at a former period, been very much colder than at present; and that this may be accounted for without supposing any different external conditions of our planet.

568. State concisely the plan you would adopt in order to ascertain the geological structure of some new locality.

569. State concisely proofs of elevation and depression of land, and mention examples in different parts of the world.

570. Explain fully, and with examples, the grounds of the three great divisions of stratified fossiliferous rocks.

571. Define gneiss, porphyry, syenite, grauwacke, tuff, travertin. How are Igneous rocks usually distinguishable from Aqueous? Explain how the age of Igneous rocks may be determined, and illustrate by any actual cases which may occur to you.

572. What is the mean density of the earth? Explain how this is established. What is that of the external crust, so far as we are acquainted with it? What is there to account for the difference?

573. Explain the terms *lamination* and *foliation*. How do you account for the lamination of some aqueous deposits, and the absence of this character in others? Give examples.

574. What proofs are there of the former occurrence of a "glacial period" in this part of the earth? What means have we of ascertaining the (geological) date of this period?

575. What proofs have we of changes of climate in this country in former times? Draw a diagram showing the direction of the principal Atlantic currents, and point out how they affect at present the climate of this country.

576. What is the composition of the magnesian limestone, and where is this formation found in Great Britain?

577. What is the nature of glaciers, and the effects they have produced on the surface of the earth?

578. Explain the action of ice as a transporting power. What proofs have we of the existence of a much colder climate in our island at no very remote geological epoch?

579. Describe the phenomena of the boulder drift of Northern Europe. Appeal to causes now observed to be in action to account for it.

580. Explain the origin of springs; also the construction of an Artesian well, and the conditions necessary to the success of such a well.

581. Define *denudation*. Give some proo
which this has contributed to the present e
earth. Explain how the action of aqueous
to bring the earth to its present figure, whatev
might have been.

582. Explain the relation between the o
springs and faults, and different kinds of strat

583. Describe the blowpipe characters of re

584. Describe the physical and blowpipe
stone.

585. How is gadolinite distinguished from
most nearly resemble it; and what are they ?

586. Name the important earthy constitue
pipe fails to detect readily.

587. Give the blowpipe characters of baryt

588. The underlay of East Pool, south l
from grass for 105 fathoms, when it reache
changes its underlay to 40° N., along the junc
and slate, for 88½ fathoms; what is the total
this point ?

589. At Pedn-an-drea mine, the underlay o
37° N., and that of Martin's lode, which lies
south of it, is 46° 30′ N. At what depth will
tersect ?

590. If a wall, whose height is a, and width
by the shock of an earthquake; prove that th
city of the shock, perpendicular to the wall, is

$$v^2 = \tfrac{4}{3}g\left(\frac{a^2+b^2}{a^2}\right)\sqrt{(a^2+b^2} -$$

591. Prove that the horizontal velocity, per
a wall, necessary to break it across at the base,

$$v = \tfrac{2}{3}g\,\frac{Lb}{a^2};$$

where L denotes the length of wall, whose wei
cient to tear it asunder.

592. In the Naples earthquake, a wall was
Barielle, whose height was 26 ft., and width 4
horizontal velocity of the shock, perpendicular
suming $L = 13$, one-fourth the coefficient fo
masonry.

593. The path of the earthwave at Barielle

cular to the wall, but its angle of incidence on the wall was 25°, and its angle of emergence from the ground was 13°; find its actual velocity from these data.

594. At Vietri di Potenza, a large stone forming one face of the water conduit, 6 ft. by 3 ft. by 1 ft., was *not* upset, the earthwave passing in a plane parallel to the face (6×3); if we assume one foot additional in the height of the block, due to the superimposed capping of the monument, and 13 ft. per second as the actual velocity of the shock, it is required to determine a major limit to the angle of emergence of the earthwave.

595. At Villa Carusso, some roof tiles were projected to a horizontal distance of 9 ft., having fallen from a height of 33 ft.; it is required to find the angle of emergence of the shock, assuming the actual velocity of the earthwave to be 13 ft. per second.

596. At the Palazzo Romani, Mr. Mallet found the angle of emergence to have been 25° 30′, and observed that a vase in the garden had been thrown from its pedestal, horizontally $6\frac{1}{2}$ ft., and vertically 3.6 ft.; it is required to find the actual velocity of shock that produced this projection of the vase.

597. State Mr. Scrope's theory of the relation between axes of elevation and axes of volcanic action; illustrate this theory by examples in detail, and show that it is founded on sound mechanical principles.

598. If a vertical columnar pillar of basalt, trachyte, or other rock, be drawn asunder lengthwise by a force P; show that it will be most easily fractured along a plane whose angle of inclination with the horizon is given by the equation

$$2i = \phi + 90°;$$

where i denotes the inclination of the plane, and ϕ the angle of friction of the rock composing the pillar.

599. Hence show, on mathematical principles, that if such a pillar be cooling from a liquid condition, and be more viscous on the outside than in the interior, its easiest surface of separation will be cupshaped, or convex downwards.

600. The percolating power of lower green sandstone beds was found by experiment to be 18 cub. in. per hour, through 15 in. of sand, in a bent pipe of $1\frac{1}{4}$ in. diameter, under a pressure of 6 in. of water. Required the area of filter beds that, under 6 in. of water, would discharge as much water as a $1\frac{1}{4}$ in. pipe running free.

601. Find the height of a column of water that would force as much water through the sand as would run through the pipe under a 6 in. head.

602. The drainage area of the Mississippi is 1,244,000 sq. m.,

and its mean annual rain-fall is 30.4 in.; its annual discharge into the Gulf of Mexico is 21,300000,000000 cub. ft. What is the proportion of the rain-fall expended in evaporation and vegetation?

603. The length of the Missouri River, from Madison Fork to the Gulf of Mexico is 4194 miles; and the height of Madison Fork above the sea level is 6800 ft. Supposing the water that leaves Madison Fork to reach the Gulf with a velocity of $1\frac{1}{2}$ mile per hour, what is the proportion of its work expended on the road?

604. Describe the physical and blowpipe characters of the oxides of iron usually employed as ores?

605. What are the blowpipe characters of copper glance and copper pyrites?

606. How do you distinguish between wolfram and tinstone by means of the blowpipe?

607. A shaft is sunk on a lode to a certain distance, when the lode is found to be separated, and thrown down by a slide; the lode is afterwards recovered by rising on the slide, and again worked. Find the total depth of the working, and the horizontal distance at which a downright shaft should be sunk to reach the end.

	Draft.	Underlay.
1st part of lode, ...	+ 114 ft.	+ 54° 30′
Slide, ...	− 32 „	− 43 0
2nd part of lode, ...	+ 73 „	+ 51 0

608. Two lodes intersect, having the following bearings and underlays:—

No. 1.	E. 5° N. . . .	64° N.
No. 2.	N. W. . . .	42° W.

Find the bearing and underlay of their intersection.

609. At Villa Carusso, some roof tiles were projected to a horizontal distance of 9 ft., having fallen from a height of 33 ft.; it is required to find the angle of emergence of the shock, assuming the molecular velocity of the earthwave to be 13 ft. per second.

610. At the Palazzo Palmieri in Polla, a mass of stone was thrown, by the return shock, a distance of 14 ft. horizontal and 30 ft. vertical. In the same Palazzo, the lintel of a "camine" was thrown, by the return shock, in the manner described by Mr. Mallet, 7.2 ft. horizontal and 5 ft. vertical. Combine these observations, so as to determine both the angle of emergence and the molecular velocity of the earthwave.

611. The bell of the church of La Sala was projected, by the return shock, 17 ft. horizontal and 26 ft. vertical; find angle of emergence, molecular velocity being 13 ft. per second.

612. In the garden of the Palazzo Romani of Padula, a circular pillar was first broken, and then thrown 9 in. horizontal and 6 in. vertical; the dimensions of the pillar being 50 in. height, and 17 in. diameter. Find the horizontal velocity requisite to produce these effects.

613. In the same place, Mr. Mallet found the angle of emergence to have been 25° 30′, and observed that a vase in the garden had been thrown from its pedestal horizontally 6½ ft. and vertically 3.6 ft.; it is required to find the molecular velocity of shock that produced this projection of the vase.

614. In the caffé of Gaetano Mallione, Moliterno, a number of bottles, full to the corks of Rosolio, stood upon a shelf 8 ft. high, and were thrown 3 ft. horizontally. Assuming these bottles at 2.8 in. diameter, and 8 in. high, neglecting the necks, find the horizontal velocity necessary to overturn and project them.

615. At Saponara, a wall of old masonry was thrown down, measuring 2.75 ft. in width, and 20 ft. in height; find the horizontal velocity, applied perpendicularly to the wall, necessary to break and overthrow it, assuming the coefficient of cohesion of the rubble masonry at 52 ft.

616. Half a mile from Saponara, Mr. Mallet found two square gate piers thrown down, measuring 3 ft. square, and 7 ft. in height; find the horizontal velocity necessary to break and overturn them.

617. In the house of Don Antonio Morano, at Tramutola, the key stone of an elliptic arch was thrown 9 ft. horizontally, and 11 ft. vertically; and in the same town, in the Capelluccio della Madonna Maria dell' Pieta, a block of stone was thrown 15.75 ft. horizontally, and 21 ft. vertically; find the angle of emergence and molecular velocity.

618. Near the monastery of Monticchio, a large block of lava was thrown horizontally 14 ft., and vertically 43 ft., the angle of emergence being 40°; find molecular velocity.

619. A wall was thrown down at Barielle whose height was 26 ft., and width 4 ft.; and the earthquake path had an incidence of 25° on the wall, and an emergence of 15°; find the molecular velocity.

620. In a proposed mineral tramroad, you are supposed to know the weights P and Q of the loaded and unloaded waggons, and the coefficient of friction is supposed to be also known; what should be the inclination of the tramroad, in order that the work on the horses shall be the same in going up and down?

621. Two lodes intersect each other, their backs making an angle of 30°, and their underlays are 18 in. and 12 in. in the fath. respectively; find by calculation, or construct on the scale of 6 in.

2. Birds,	Insects,	Gasteropods,
3. Reptiles,	Crustaceans,	Lamellibranc
4. Fishes,	Annulates,	Molluscoids,

founded on the predominance of the nervous s apparatus, organs of nutrition, and reproducti tively.

Illustrate in detail this principle of classific Sub-kingdoms, and give examples, either fossil

623. State the classifications of the Animal] by Aristotle, Pliny, and Linnæus.

624. Describe the osteological peculiarities of tiles, and the inferences that may be drawn cation and gait from the structure and shape femur.

625. Demonstrate, by comparison of the vario and recent reptiles, the existence in former tim and more highly organized forms than are found

626. Describe the peculiarities of the struct nodon.

627. Contrast the structure of the shoulder jo in the Plesiosaurus, describing the bones that en position of each.

628. What reasons are there for believing th have been a more highly organized Reptile th saurus?

629. State in detail what you know of the

3. Describe the physical, chemical, and pyrognostic charac-
of Pitchblende.

4. With what minerals is Wolfram liable to be confounded;
iow may it be distinguished by physical and pyrognostic
icters?

5. Name the ores of iron; and state the principal mines
us for the production of each.

6. Describe the quantitative method of ascertaining the
int of Arsenic in a specimen of Mundic.

7. A lode bears E. 20° N. and underlays 64° N., and is in-
cted by another lode bearing N. 32° E. whose underlay is
S. Find by construction the intersection of these lodes, and
nderlay.

8. Verify the preceding construction by calculation.

9. Given the following course of traverse dialling, made with
t-hand dial; find the distance and bearing of the end.

No.	Draft.	Bearing.
1	36.00	162°
2	44.33	143¾
3	30.75	16½
4	28.50	257¼
5	17.83	45
6	15.25	7¾
7	72.00	152½
8	16.00	87½
9	73.00	204½

o. A course of traverse dialling gave the following results;
ılate the length and bearing of the end:—

No.	Draft.	Azimuth.
1. . .	95 fm. . .	20° E. of N.
2. . .	207 ,, . .	49 S. of E.
3. . .	51 ,, . .	34 W. of N.
4. . .	101 ,, . .	19 W. of N.
5. . .	11 ,, . .	9 W. of N.

1. It is intended to sink a shaft on the end of a level driven

from Pendarves' shaft, and the following is the survey
centre of Pendarves' shaft to the end of the level :—

No.	Draft.	Azimuth.
1. . . .	45 fm. . . .	3° W. of N.
2. . . .	$24\frac{1}{2}$,, . . .	$7\frac{1}{4}$ N. of E.
3. . . .	18 ,, . . .	$8\frac{1}{2}$ N. of E.
4. . . .	49 ,, . . .	E.
5. . . .	30 ,, . . .	12 S. of E.

Find where the new shaft should be sunk.

642. Name the mineral described thus by Dr. Smi
your reasons :—

"Hardness = 5. Powder, dark iron-grey. On c
emits some white fumes with slightly pungent odour,
readily into a black bead, not magnetic, which is br
breaks with metallic lustre; this bead, fused with bora
it deep blue in the outer flame, and alloys with the
wire; and in the inner flame the blue colour is chang
brownish amethyst shade."

643. Give the blowpipe characters of Pitchstone and

644. Give the distinguishing characters of the Nauti
thoceratidæ, and Ammonitidæ.

645. Give the characters of Terebratulidæ, Spiriferid
chonellidæ, Orthidæ, and Productidæ.

646. State the geological history of the principal fa
Cephalopods and Brachiopods.

647. In what respects do the marsupial bones of the
rium differ from those of living Didelphs?

648. State and prove Clairaut's Theorem, on the su
that the earth is composed of ellipsoidal layers, of sm
ticity, whose density varies according to any law, and
assuming the original condition of the earth to ha
fluid.

649. Deduce from this theorem the figure of th
surface, on the suppositions of homogeneity, and infinit
at the centre; assuming its original fluid condition.

650. Some geologists have supposed that, if the ea
originally spherical (with a mean density of $5\frac{1}{2}$, and su
density of $2\frac{3}{4}$), it may have attained its present elliptici
by the mere action of the sea and atmosphere upon t

Show, by means of Clairaut's Theorem, that this supposition is inconsistent with the laws of mechanics and hydrostatics.

651. Deduce the mean density of the earth from the following considerations:—

(*a*). Mr. Airy's experiments on the seconds' pendulum in the Harton coalpit showed that the pendulum gained $2\frac{1}{4}$ seconds per day at the bottom of the pit.
(*b*.) The pit was 1260 ft. deep.
(*c*.) The mean level of the land is 1000 ft.
(*d*.) The area of land to sea is as 1 : 5.815.
(*e*.) The mean density of the land is 2.75.

652. State the phœnomena of Joints and Cleavage; and show that all these phœnomena, including those of Conjugate and Secondary Joints, can be simply explained on mechanical principles.

653. State the Rev. Canon Moseley's theory of glacier motion.

654. A granite is composed of—

(*a*.) Pure Silica,	25	parts.
(*b*.) Pure Orthose,	61	,,
(*c*.) Mica,	14	,,
	100	,,

and the mica has the formula

$$KO, SiO_3 + 3\,(Al_2O_3,\ SiO_3).$$

Calculate the ultimate composition of the Granite.

655. A Syenite is composed of Anorthite and Hornblende, and they have the following compositions:—

	Anorthite.	Hornblende.	Syenite.
Silica,	45.87	50.72	47.52
Alumina,	34.73	9.36	28.56
Lime,	17.10	16.97	15.44
Magnesia,	1.55	2.40	1.48
Protoxide of Iron,	....	18.61	7.23
	99.25	98.06	100.23

Find the percentage mineralogical composition of this Syenite.

656. The Granites of Leinster contain Quartz, Orthoclase, and Margarodite; show from the following average analyses that they must also contain other minerals:—

	Granite.	Orthoclase.	Margarodite.
Silica, ...	72.07	64.59	44.58
Alumina, ...	14.81	18.31	32.13
Peroxide of Iron, . .	2.22	....	4.49
Lime, ...	1.63	0.25	0.78
Magnesia, ...	0.33	0.58	0.76
Potash, ...	5.11	12.23	10.67
Soda, ...	2.79	2.75	0.95
	98.96	98 71	94.36

657. Assuming that in a cleaved rock what was originally a sphere has become an ellipsoid, whose semiaxes are a, b, c; that the axis of x is the intersection of the planes of cleavage and bedding; that the axis of z is perpendicular to the cleavage plane, and that the axis of y lies in the dip of the cleavage plane; show that the amount of compression which has produced the cleavage may be calculated by means of the following equations:—

$$\frac{1}{b} = \sqrt{\frac{\left(\frac{\sin\phi}{\rho'} + \frac{\sin\phi'}{\rho}\right)\left(\frac{\sin\phi}{\rho'} - \frac{\sin\phi'}{\rho}\right)}{\sin(\phi+\phi')\sin(\phi-\phi')}},$$

$$\frac{1}{c} = \sqrt{\frac{\left(\frac{\cos.\phi'}{\rho} + \frac{\cos\phi}{\rho'}\right)\left(\frac{\cos\phi'}{\rho} - \frac{\cos\phi}{\rho'}\right)}{\sin(\phi+\phi')\sin(\phi-\phi')}};$$

in which ϕ, ϕ', are the angles between cleavage and bedding in two localities of the same district; and $\frac{1}{\rho}$, $\frac{1}{\rho'}$, are the *distortions* of fossils in the same localities, estimated parallel to the intersection of the planes of cleavage and bedding.

658. A lode bears 15° N. of E., and dips N. 70°; and it is intersected by another lode bearing 17° S. of E., which dips S. 60°. Find their line of intersection.

659. From the depth of 50 fms. in an engine shaft, a crosscut was driven which pierced a lode after being driven 15 fms.; this lode was found to underlay 40° towards the engine shaft. Find the depth at which the shaft will intersect the new lode, and the length of the latter between the two intersections.

660. Borings for coal are made at A, B, C, and coal is found at 100 ft. (A), 120 ft. (B), and 110 ft. (C); find the strike and dip of the coal bed, being granted that AB = 340 ft., AC = 370 ft., and BC = 400 ft.

661. Give the blowpipe characteristics of pitchstone, and of basalt.

662. Give the blowpipe characteristics of garnet, and of ruby.

663. Give the blowpipe characteristics of spodumene, and of oligoclase.

664. Name the mineral exhibiting the following reactions:—

(*a.*) Effervesces feebly with nitric acid.

(*b.*) Decrepitates in the forceps, and fuses readily into a very fluid globule, transparent while hot, white and opaque when cold, and tinges the flame behind the assay pale greenish yellow.

(*c.*) With borax fuses rapidly, with effervescence, into a glass opaque when cold, if saturated with the assay.

THE END.

[illegible]